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ORIGINAL ARTICLES.

The Zonal Nomenclature of the Upper Kimmeridge Clay.

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PREVIOUS to the year 1913 the English Kimmeridge Clay was divided into two zones only, which were believed to be "intimately blended".[1] In 1913 Dr. H. Salfeld [2] instituted a more detailed subdivision of eleven zones, the upper three of which constitute the Upper Kimmeridge Clay as since defined by Dr. F. L. Kitchin.[3] Salfeld's sequence of zones was emended in 1922 by Messrs. Chatwin and Pringle,[4] who showed that at Swindon the zone of *Pectinatites pectinatus* (Phill.) occurs below the Swindon Clay, and not above it, as Salfeld had supposed. In the early part of last year Mr. S. S. Buckman [5] also presented a similar scheme of zones, and subdivided Salfeld's zone of *P. pectinatus*, which he placed in the Lower Portland, as in Salfeld's original scheme.

The ammonites of the Upper Kimmeridge Clay, for long known by the comprehensive name "*Ammonites biplex*" auctt. (*non.* Sow.), have been identified in recent years with the Russian form *Ammonites pallasianus* d'Orb. and its allies. A detailed investigation, however, discloses that the English ammonites have no direct relation with the Russian forms, and are probably of later geological age. The

[1] H. B. Woodward, "The Jurassic Rocks of Britain"; vol. v, "The Middle and Upper Oolitic Rocks of England": *Mem. Geol. Surv.*, 1895, p. 152.

[2] H. Salfeld, "Certain Upper Jurassic Strata of England": *Q.J.G.S.*, vol. lxix, 1913, p. 423.

[3] F. L. Kitchin, "The Faunal Characters and Correlation of the Concealed Mesozoic Rocks in Kent"; Summary of Progress Geol. Surv. for 1918, p. 43: *Mem. Geol. Surv.*, 1919.

[4] C. P. Chatwin and J. Pringle, "The Zones of the Kimmeridge and Portland Rocks at Swindon"; Summary of Progress Geol. Surv. for 1921, p. 162: *Mem. Geol. Surv.*, 1922.

[5] S. S. Buckman, *Type Ammonites*, vol. iv, 1923, pp. 29, 33.

Upper Kimmeridge fauna is rich in ammonites; so far, twenty-five species have been described (in MS.) by the present writer, and these are distributed among eight genera of which six are new. Besides these, several species have been figured by Mr. S. S. Buckman from the arenaceous facies of Swindon and Oxford.

As some time must necessarily elapse before complete publication of the writer's work on the Upper Kimmeridge ammonites, a summary of the proposed zonal nomenclature will probably, in the meantime, be useful to other workers.

The following table indicates the proposed series of zones, together with the zonal scheme hitherto used :—

TABLE I.

Suggested Zones.	Salfeld, 1913, *emend.* Chatwin & Pringle, 1922.	Buckman, 1923.
5. *pallasioides* .	*pallasianus* and *lomonossovi*	"*pallasianus.*"
4. *rotundum* . .		"*lomonossovi.*"
3. *pectinatus*. .	*eastlecottensis*	[Included in Lower Portland Sands above "*pallasianus.*"]
2.	*Virgatites* spp.	*scruposus.*
1.		"*Aulacosphinctes.*"
		"*dorsoplanus.*"

The lowest horizon mentioned in Table I succeeds the Gravesia zones of the Lower Kimmeridge Clay. Of the five faunal horizons now recognized, the lower two cannot be named until the ammonites are figured. These horizons may now be considered in detail.

1. The ammonites hitherto identified as species of *Virgatites* Pavlov, have no connexion with Pavlov's genus or with *Aulacosphinctes* Uhlig, but represent two distinct lineages, homœomorphic with these "genera". It may be stated that *Virgatites* has not been found by the writer in the English deposits here considered; and, moreover, since the Russian form is probably earlier, it seems probable that the Virgatites zone as such does not exist in England. There seems to be no evidence at present to justify the subdivision of this zone[1] into "Aulacosphinctes" and "dorsoplanus" horizons, since the fauna of the Shotover Nodule Bed is sometimes found in the clays above, and ammonites hitherto identified by both these names are found in the Nodule Bed itself. This lowest zone of the Upper Kimmeridge Clay is exposed in the type-section of Kimmeridge Bay (between the Yellow Ledge and the Oil shales) and in brickfields at Culham, Chawley, Shotover Hill and Wheatley in Oxfordshire, and at Swindon (Hill's brickyard). This horizon also occurs in Lincolnshire and at Speeton, but the higher zones are missing.

2. Mr. J. Pringle has obtained fragmentary specimens of large ammonites from the Oil shales of Corton, and these have been

[1] S. S. Buckman, *Type Ammonites*, vol. iv, 1923, p. 33.

recorded [1] as *Pseudovirgatites scruposus* Vetters. A similar specimen showing part of the inner whorls was found by the writer in clay immediately below the so-called "Portland Sands" at Shotover Hill. These ammonites, though externally similar to *Pseudovirgatites*, apparently have no relation with this genus, but are probably a development of a lineage from zone 1, in which the primary ribs are greatly accentuated and appear (in the most advanced form) as elongated tubercles. The crinoid *Saccocoma* appears just below the Oil shale horizon of Kimmeridge, and its wide distribution has justified its use as an index of horizon.[2] The crinoid, however, has a greater vertical range than the ammonites, and continues into the zone next above. Zone 2 (the "scruposus" horizon of Buckman) is still imperfectly known, the characteristic ammonites having been collected only at Corton and Shotover Hill.

3. The roof of the "seam of Kimmeridge Coal" has yielded pyritized ammonites of the genus *Pectinatites* Buckm. (viz. *P. aulacophorus* Buckm., and a new species) which were recorded by Hudleston [3] as *Perisphinctes pectinatus* (Phill.). These ammonites occur 8 or 10 feet above zone 2, but still within the Saccocoma horizon.[4] At Swindon, Messrs. Chatwin and Pringle [5] record similar ammonites from the sands below the Swindon Clay, and these have been figured by Mr. S. S. Buckman [6] as *Pectinatites pectinatus* (Phill.) and *P. aulacophorus* Buckm. Species of *Wheatleyites* ("Ammonites of eastlecottensis type" [7]) also occur in these beds, together with an abundant lamellibranch fauna.[8] The so-called "Portland Sands" of Shotover Hill and Wheatley also yield species of *Wheatleyites* and *Pectinatites* and the writer has collected many lamellibranchs from these beds, including:—*Pecten* (*Syncyclonema*) *nitescens* Phill. sp., *Pecten* (*Camptonectes*) *morini* de Lor. sp., *Astarte* sp. cf. *sæmanni* de Lor., *Astarte* sp. cf. *mysis* d'Orb., *Trigonia pellati* Mun.-Chalm., *Protocardia morinica* de Lor. sp., *Thracia* cf. *incerta* Thurmann sp., *Pleuromya* (two species), *Lima* sp., *Grammatodon* sp., *Perna* sp. (impression of hinge). This fauna, which is identical with that of the pectinatus zone of Swindon, is characteristic of t e upper part of the Kimmeridge Clay, most of the forms having long been known from the Hartwell Clay of the Aylesbury district. The evidence provided by the ammonites shows that the upper portion of the Kimmeridge Oil-shale horizon should be correlated with the "Portland Sands" of Shotover and Swindon, as pointed out long ago for the latter

[1] In Buckman, *Type Ammonites*, vol. iv, 1922, p. 17.
[2] F. L. Kitchin, op. cit., 1919, p. 43.
[3] W. H. Hudleston, "Excursion to Swanage, Corfe Castle, Kimmeridge, etc.": *Proc. Geol. Assoc.*, vol. xiv, 1896, p. 322.
[4] Information from Mr. J. Pringle.
[5] C. P. Chatwin and J. Pringle, op. cit., 1922, p. 166.
[6] S. S. Buckman, *Type Ammonites*, vol. iv, pl. 381.
[7] S. S. Buckman, *Type Ammonites*, vol. iv, 1923, p. 28.
[8] C. P. Chatwin and J. Pringle, op. cit., 1922, p. 166.

locality by Hudleston [1] and more recently by Messrs. Chatwin and Pringle.[2] Mr. Buckman,[3] however, places these beds above the Hartwell Clay, between it and the Portland Stone Series, but it is significant that the Hartwell Clay ammonite-fauna has never been found below these "Portland Sands", as Mr. Buckman has already pointed out. The sands of the pectinatus zone have apparently been confused with sands of similar appearance which occur above the Hartwell Clay in the Aylesbury district. This arenaceous facies of the Upper Kimmeridge Clay is here considered (for convenience) as a whole, though Mr. Buckman has shown that it is capable of subdivision.

4. Above the Bituminous shales in the Kimmeridge cliff-section is a thick series of clays containing innumerable ammonites in a crushed condition. Occasional cement-stone nodules, however, provide uncrushed specimens, notably at Chapman's Pool. An exceptionally fine series of these ammonites has been collected by Mr. J. Pringle for the Geological Survey, and this material was kindly lent to the writer for description. A common species is "*Perisphinctes*" *rotundus* (Sow.) which has been taken as the genotype of a new genus *Pallasiceras* by Dr. L. F. Spath. This ammonite will serve to mark the horizon. Several other species of *Pallasiceras* occur associated with *P. rotundum*. A similar fauna has been collected in brickfields at Long Crendon (now abandoned) and Hartwell, also in a temporary excavation (at a depth of 18 feet) at Aylesbury. At these localities the ammonites attain an exceptionally large size. The basal portion of the Swindon Clay, consisting of a hard, greenish marl, contains fragments of ammonites which appear to be referable to *Pallasiceras*, and poorly preserved specimens are occasionally found in the blue clay which forms the mass of the Swindon Clay.

The rotundum fauna is also present in the phosphate-bed overlying the Swindon Clay in the Okus Quarry at Swindon. Many of the fragments found here represent only the body-chamber, but some are septate and show the characteristic suture-line of *Pallasiceras*. As portions of the test still adhere to the phosphatic cast in many cases, it is considered that the fauna is derived from the upper portion of the Swindon Clay, which was denuded by the scouring action of currents during the time when the Hartwell Clay was being deposited elsewhere. Thus the Swindon Clay as a whole represents the rotundum zone of Chapman's Pool and Long Crendon. The Hartwell fauna is not represented at Swindon. Rolled fragments of *Pallasiceras* are also found in the Lower Greensand of Faringdon and Woburn.

The "Littleworth Lydite Clay" of Wheatley in Oxfordshire

[1] W. H. Hudleston, op. cit., 1896, p. 162.
[2] C. P. Chatwin and J. Pringle, op. cit., 1922, p. 162.
[3] S. S. Buckman, *Type Ammonites*, vol. iv, 1923, p. 37.

is probably on the rotundum horizon. Ammonites are scarce and in a poor state of preservation, but apparently belong to the genus *Pallasiceras*. The deposit also corresponds in stratigraphical position with the Swindon Clay, i.e. it rests upon sands of the pectinatus zone. The presence or absence of lydites is not considered to be of correlative value, but probably is the result of local conditions of deposition, since such pebbles occur sporadically throughout the Upper Kimmeridge Clay of various localities.

5. The succeeding beds of the Kimmeridge Clay contain ammonites that are usually identified as *Perisphinctes pallasianus* (d'Orb.), a form originally described from the Lower Volgian series of Russia. The ontogeny of the ammonites and the characters of their adult suture-lines preclude any direct connexion between the English and the Russian forms. Two ammonites already figured are characteristic of this zone, viz. *Holcosphinctes pallasioides* gen. et sp. nov. (= *Am. biplex* H. B. Woodward, Middle and Upper Oolites: *Mem. Geol. Surv.*, p. 156, fig. 72, 1895), of which specimen No. 30721 Coll. Geol. Surv. is genotype and holotype, and *Aposphinctoceras decipiens* gen. et sp. nov., of which the genotype and holotype is *Olcostephanus pallasianus* var. nov. Healey, figured in *Q.J.G.S.*, vol. lx, 1904, p. 60, pl. xii, figs. 1 and 2. The former species is taken as the zonal index.

The pallasioides zone has long been known as the Hartwell Clay in Buckinghamshire, where it is worked for brickmaking at Aylesbury, Hartwell, Bierton, and Whitchurch. This horizon is not known at Wheatley, where the beds immediately above the "Littleworth Lydite Clay" are not exposed, about 15 feet being hidden in the hillside. In the type-section of the Isle of Purbeck the clays above the rotundum zone have yielded ammonites similar to *H. pallasioides* (though in a poor state of preservation), and the lower portion at least of the overlying sands may, for the present, be included in the pallasioides zone. The whole of the "Portland Sands" of this locality and the Isle of Portland should be taken as the uppermost part of the Kimmeridge Clay, the lower limit of the Portland being drawn at the base of the "Limestones with Chert". This was the view of Blake [1] who proposed the term "Bolonian" to include the Upper Kimmeridge Clay and the Portland Sands, but the term has not met with general acceptance, and appears to be unnecessary. The fauna of these sands has still to be worked out, but Blake [2] records "*Ammonites biplex*" and lamellibranchs of Kimmeridgian aspect. Apparently then, there is no palæontological break between the Upper Kimmeridge Clay

[1] J. F. Blake, "On the Correlation of the Upper Jurassic Rocks of England with those of the Continent"; Part I, "The Paris Basin": *Q.J.G.S.*, vol. xxxvii, 1881, p. 584.

[2] J. F. Blake, "On the Portland Rocks of England": *Q.J.G.S.*, vol. xxxvi, 1880, pp. 193, 195.

TABLE II.

Zones.	Kimmeridge Bay.	Swindon.	Wheatley.	Long Crendon.	Aylesbury.
(?)	"Portland Sands."	Represented by phosphate-bed.	Littleworth Sands.	Sands below lydite-bed.	Sands with lydites.
5. *pallasioides* . .	Sandy clays with crushed ammonites (Emmot Hill and Henstout).		Not exposed (? hidden in hill).	Absent.	Hartwell Clay (base not seen).
4. *rotundum* . .	Clays with nodules at Chapman's Pool. White Septarian Band.	Swindon Clay (sandy at base).	Littleworth Lydite Clay.	Clay in brickfield (base not seen).	
3. *pectinatus* . .	Top part of oil-shale with pyritized ammonites.	Sandstone and sand with doggers.	Shotover Grit Sands. Wheatley Sands.		
2. [Ammonites not yet figured.]	Oil-shales.	(?)	Clays at Shotover and Wheatley.		
1. [Ammonites not yet figured.]	Shales between Oil-shales and Yellow Ledge.	Clays at Hill's brick-yard.	Clays and Nodule Band.		
	Lower Kimmeridge Clay.				

and the overlying sands. The conclusion of Dr. F. L. Kitchin[1] with regard to the Upper Kimmeridge Clay in Kent may aptly be quoted here :—"We conclude, on palæontological grounds, that the top of our Upper Kimmeridge Clay corresponds with the top of the Portland Sands in Dorset, and it is evident that in Kent the deeper water argillaceous conditions persisted during the time when in some other parts of the country there was an impure and sandy facies connected with shallowing, towards the close of the Kimmeridgian epoch. Hence, we have classified no part of the Kentish series as Portland Sand."

The following diagram and the table of correlation (p. 150) will serve as a summary of the views advocated above :—

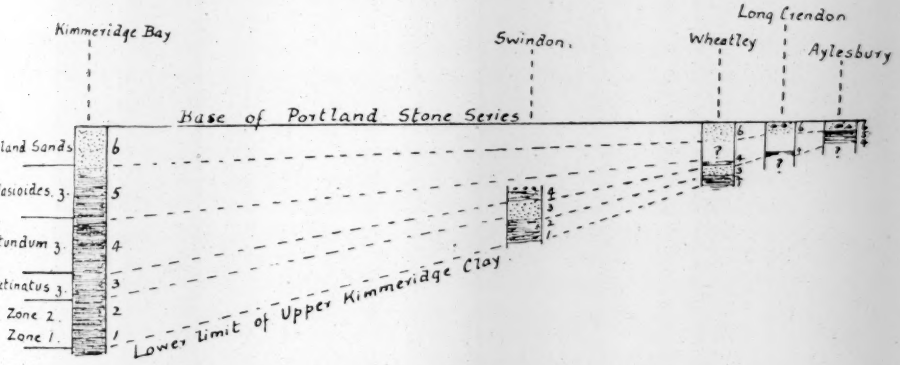

FIG. 1.—Diagrammatic representation of sections detailed in Table II.

During the progress of this work matters of detail have been discussed with Professor A. Morley Davies, Dr. F. L. Kitchin, Dr. L. F. Spath, Messrs. C. J. Bayzand, S. S. Buckman, C. P. Chatwin, E. Hollis, and J. Pringle. Material has been lent by Dr. L. F. Spath and Mr. J. W. Tutcher, while facilities for investigating material in the Natural History Museum, the Museum of Practical Geology, and the Bucks County Museum (Aylesbury) have been readily granted. The expense of collecting material has been defrayed in part by a Grant from the Royal Society Committee. The laboratory work has been carried out in the University of Liverpool. The writer desires to tender his grateful acknowledgments for this assistance.

[1] G. W. Lamplugh and F. L. Kitchin, "On the Mesozoic Rocks in some of the Coal Explorations in Kent": *Mem. Geol. Surv.*, 1911, p. 204. See also G. W. Lamplugh, F. L. Kitchin, and J. Pringle, "The Concealed Mesozoic Rocks in Kent": *Mem. Geol. Surv.*, 1923, p. 227. This volume was issued after this paper was written.

The Probable Solution of the Climate Problem in Geology.

By Wilhelm Ramsay, Professor of Geology and Mineralogy at the University of Helsingfors, Finland.

I.

In the following pages I have endeavoured to give an interpretation, not only of the appearance of ice ages, but also of the greater changes of climate registered in the geological record. In view of the importance ascribed in this discussion to relief, I have named the theory the relief hypothesis.[1]

Kindred explanations have been put forward before. Lyell would find the causes of the great alternations of climate during past ages in the continuous changes of the distribution of land and sea which had been going on all through the geologic ages. J. G. Charpentier, in the first half of the nineteenth century, supposed that the glaciation of the Alps and other tracts had been greater formerly because these were much more elevated. Since then various hypotheses of continental elevation have been set forth as solution of the climate problem in geology. It is easy to discover the weak points in these suggestions and to understand why they have not been found applicable. But there is one strong point in all of them. They have looked for the causes of the geologic changes of climate in geographic changes which the earth may have undergone. The relief hypothesis follows the same lines.

This theory does not explain why ancient glacial formations, such as the Permian, are now found far from the poles, often near the equator. In order to understand this and other very anomalous situations of climatic zones of the past, one can hardly avoid postulating migrations of the poles or the continents.

The question to be answered here is :—

Why have some geological periods been characterized by glaciation and various other signs of cooler climate, while the earth in other periods was favoured with very warm climates which extended their influence apparently to all parts of the globe ?

The very question arises from our knowledge that geological evolution has not been uniform. On the contrary, as is commonly understood and admitted, orogeny, volcanism, degradation, and aggradation, and all other constructive and destructive processes show great differences in their intensity from period to period, and these variations are cyclic and rhythmic. The measure of the rhythm is indicated by the formation of the mountain chains.

Since the beginning of the Cambrian period, the evolution of the earth has passed through three geologic cycles of higher order and commenced a fourth. The transition from one to another is marked by the unconformities which in the stratigraphical series

[1] Wilhelm Ramsay, " Die Reliefhypothese zur Erklärung der Klimaschwankungen " : *Petermanns Mitteilungen*, 1911, p. 335.

follow the Caledonian, Hercynian, and Alpine diastrophism. The great cycles are :—

	Part 1.	Part 2.	Main Orogeny.
Cycle I.	Eocambrian–Cambrian–Ordovician.	Gothlandian.	*Caledonian.*
„ II.	Devonian–Lower Carboniferous.	Upper Carboniferous.	*Hercynian.*
„ III.	Permian–Triassic–Jurassic.	Cretaceous–Tertiary.	*Alpine.*
„ IV.	Quaternary.		

The first part of each cycle comprises an anorogenic phase of long duration. The cycles enter then in a first orogenic phase, a forerunner of the main mountain-making movements. After this, relatively anorogenic periods follow in the second part of each cycle. From this point, however, disturbances become more frequent, and at the end of the cycle, the main mountain-folding takes place, to continue here and there, with decreasing strength, in the beginning of the following cycle.

The above tabulation in cycles of the geological periods is in no manner meant to assert that these were of equal duration, nor that the corresponding phases from different cycles represent quite similar stages in geological evolution. It is of course possible to dispose the periods in cycles in many other ways, But however we arrange them, we shall find that the rhythm of orogeny has regulated the general course of the history of the earth.

Thus, volcanic activity has always been not only geographically combined with the zones of folding and faulting, but also chronologically connected with the formation of mountain chains, being strongest during, and immediately after, orogenic times, feeblest in anorogenic periods.

The great transgressions and regressions of the sea follow the same rhythm. In the periods of orogeny and immediately after there is considerable general regression. The land areas were extensive then, as they are at present. The greatest transgressions, again, appeared in the anorogenic intervals.

The relief of the continents has also changed in accord with the orogenic rhythm, a fact of special interest for the theory put forward in this paper.

The mountain folding, and all events in connexion with it, brought the various parts of the earth's crust into positions which no longer corresponded to the previously existing isostasy. In consequence of this, there was again a tendency to new isostasy, resulting in elevations here and depressions there. These displacements were greatest after the diastrophism at the end of each cycle, while features hitherto prevailing in the aspect of the continental blocks were replaced by new ones.

The great disturbances enormously changed the relief of the foregoing period. Thus, at the beginning of a new cycle, not only

were the land areas greater than at other times, they were also more elevated, and it was then that the loftiest mountains rose on the continents. Then, too, the sea had its greatest depth. For only so could it, in spite of its reduced area, contain the same masses of water.

The Quaternary period and the Recent time belong to such an era of high continents and deep oceans. The mountains, only formed in the later part of the Tertiary period, are still lofty, and in all continents there are old peneplains in which a young erosion has carved new valleys. This phenomenon is so common that all examples of typical peneplains referred to in literature are pre-Quaternary ones. This signifies, first, that before the crustal movements by which the different portions of the continents came in their present level, the land masses had been in a state of relative repose for so long a time that they were completely degraded, and secondly, that the altitude of most parts of the continents is at present greater than in the pre-Quaternary time. Indeed, we find undisturbed Tertiary marine deposits at high levels, and the most elevated of them belong to the oldest Tertiary beds, while younger occur at lower levels. Even Pliocene deposits lie at many places high above the beaches of both recent and Quaternary seas.

It is not astonishing that the elevation of the continents, with their highlands and mountains, reached its greatest altitude in Quaternary time. We may call to mind that tangential movements were still going on during this period in many mountains, and many remarkable faultings are equally young. Further, the now existing valleys were formed in Pliocene and at the beginning of Pleistocene time, as is well known and often emphasized. It is very probable, as Nansen [1] suggests, that in consequence of this erosion the mountain-ridges may have been raised by isostatical upheaval to levels higher above the sea than those at which the summits of the mountains stood before the erosion began.

There is thus good evidence that the relief of the continents gradually grew higher and more uneven in the course of the Pliocene and Pleistocene ages, and that the elevation of the mountains over the valleys, of the highlands over the lowlands, and of the continents over the sea, reached its maximum in the beginning of the Quaternary period, whereafter it has rather diminished. By analogy, we have the right to assume that the continents also had their highest and most mountainous reliefs at the beginning of the elder, i.e. of the Caledonian, Hercynian, and Alpinian cycles. Likewise, the relief must, in higher or lower degree, have been elevated and mountainous at the orogenic phases within the cycles, though not so high as after the three chief ages of diastrophism.

During the long anorogenic phases of the cycles, the mountains and hills were broken down and the continents finally peneplained.

[1] Fridtjof Nansen, "The Strandflat and Isostasy": *Videnskabsselskabets Skrifter: I. Mat.-naturv. Klasse*, 1921, No. 11, Kristiania, p. 305.

The changes of relief show themselves also in the nature of the sediments. Conglomerates, sandstones, grits, and other coarse clastic rocks prevail in the systems deposited during and after the orogenic phases. They testify to the activity of running water with strong power of erosion and transport, i.e. that the ground was high and sloped considerably. In the systems from the end of the anorogenic phases, again, muddy deposits and limestones are predominant. The rivers did not bring coarse material down to the sea, in many cases not even finest mud, since the land was low and plain.

The above suggestions concerning relief in the past and present may be briefly summed up.

Geological events have not proceeded uniformly, but cyclically. There were not at all ages lofty mountains and highlands in some regions, with plain lowlands, or even lower mountain districts, in others, as it is the case nowadays. For the formation and destruction of mountains has not kept a certain equilibrium during all time. In some periods the former, in others the latter process was prevailing. Only after the orogenic phases was the relief comparable to that of the present day, or still higher and more broken. For such a condition I will use the term *orocratic*. During anorogenic periods, again, the continents became more or less peneplained. I call such a condition *pediocratic*. Of course, there are gradual transitions between these two kinds of relief.

The changes of climate can also be fitted into the frame of the geological cycles.

In some ages in the history of the earth ice-caps have covered vast areas, just as in recent times. I have named such periods *miothermic* or less-warm.[1] This term may also be used to designate the less-warm climate and the corresponding deposits. In most geological systems, however, we do not find any traces of glacial formations or other phenomena evidencing a cold climate. There is rather every indication of favourable conditions for animal and plants over all the earth. For the corresponding periods and conditions, I have proposed the name *pliothermic* or more-warm. We are now living in a miothermic period. It includes not only the Quaternary ice age, but also the inter-glacial and post-glacial ages. For during them all, ice-caps and glaciers existed. An ice age signifies aggravated miothermic conditions.

Which periods were miothermic, which pliothermic ?

Traces of glaciation in the shape of tillite are found in pre-Cambrian formations. We know them, further, from the base of the Paleozoic series, and in the Eodevonian, Permian, perhaps in the oldest Cretaceous, and finally the Quaternary. They are formed in periods immediately after the great orogenic events, when the relief was orocratic. All other periods are pliothermic,

[1] Wilhelm Ramsay, "Orogenesis und Klima": *Öfversigt af Finska Vetenskaps-Societetens Förhandlingar, Helsingfors*, lii, 1910, Afd. A, No. 11.

and the obvious warmest coincide with the phases of least disturbance of the earth's crust and the greatest general transgressions, when the continents had the most pediocratic relief. Between orogeny and climate, there is an evident connexion which I pointed out some years ago (1910). ("Orogenesis und Klima" cited above.)

Bacqué, who has elaborated this theme in still greater detail, has in his instructive treatise on paleogeography [1] illustrated graphically the changes of climate from the Cambrian time to the present day and the intensity of the orogenesy during the same space of time. Those interested will see in the diagrams in the work cited (pp. 432 and 449) a striking parallelism between these two curves.

How may the apparent relation between the formation of mountains and the deterioration of climate be interpreted ?

It is hardly possible to explain it by astronomical theories concerning the ice ages, unless one supposes that the plication of mountain chains depends upon those astronomic constellations which have been thought to cause decline of heat on the earth's surface.

The hypotheses which find the cause of the ice ages in a protracted decrease of radiation from the sun, help us no more, for it is not probable that orogenesis on the earth is produced by such a change in the sun.

It thus remains to look for the answer to the above question in circumstances connected with orogenesis which have the effect that the earth is less heated by the radiation from the sun than if mountain-making had not happened.

The carbonic acid hypothesis (Arrhenius) will here come under consideration. But an examination will show that no such diminution in the supply of carbonic acid as the theory requires to explain the severer climate, i.e. lessening of volcanic activity, happened in the miothermic ages. On the contrary, volcanism was most powerful during the orogenic phases and immediately after them, while again, it was least active during the anorogenic and pliothermic periods. Thus, even for these reasons alone the carbonic acid theory is not applicable.

The simplest and most probable interpretation of the connexion between orogeny and climate lies therein, that the orocratic relief which the continents had after an orogenic phase, influenced the climate in such a manner as to establish miothermic conditions. When, again, the continents were pediocratic, as in anorogenic times, the climate became pliothermic.

It is well known that a climate is modified by the relief and the elevation of a region, and that with increasing altitude it gradually becomes cooler and even glacial. Further, mountains and highlands exercise a great effect as condensers of precipitation,

[1] Edgar Bacqué, *Grundlagen und Methoden der Paleogeographie*, Jena, 1916.

as boundaries of climate, etc. But meteorologists and geologists reflect less often that the relief of the continents influences not only the local or regional climate, but the whole economy of the calories which the sun supplies. In the paper cited, "Orogenesis und Klima," I have endeavoured to show that the influence of relief on the climate can be remarked in the following circumstances.

1. The more the radiation from the earth can be retarded, the more the temperature rises. In this storing of heat the atmosphere plays the chief part by its selective absorption, the effect of which has been compared with that of the glass on the hotbed. It yields the most favourable result on extensive lowlands, and if all continents were pediocratic, as supposed for pliothermic periods, they would profit by the sun's heat at the highest temperature. But this so-to-say ideal thermical state is disturbed by an orocratic relief. The air-mantle upon the mountains and highlands is thinner and less dense than the atmosphere over the lowlands. In consequence, insolation certainly is greater, but the loss of heat by radiation into space has increased in a much higher degree. Moreover, as in all mountain regions the rising of warm and sinking of cold air are enhanced by the greater insolation and radiation, the loss will thus be accelerated. In the above comparison with the glass on the hotbed, the lofty parts of the continents can be regarded as holes in the glass. They not only chill the place just beneath them, but more or less the whole hotbed.

2. The orocratic relief augments the loss of heat still further by its influence on the circulation of air along the surface of the earth. The air currents, passing over mountains, high coasts, and other elevations in their way, are compelled to rise, and at the higher position their loss of heat by radiation is greater than if they had flowed at a lower level. When descending on the other side of the heights they hold less heat than when they rose, even if one takes into consideration the dynamic heating of falling winds.

3. On their way uphill, the air-currents get their temperature lowered and a great part of their vapour condensed. In consequence, rain and snow fall more frequently and abundantly when the relief is orocratic, than they must do in periods when the relief is pediocratic. With the increased precipitation the temperature also is lowered. For the calories which the condensation sets free are but a compensation for the dynamic cooling of the air, and for the loss by radiation into space, and the fallen rain and snow, having normally a lower temperature than the air near the ground, demand great quantities of calories for their heating and evaporation.

If, again, the relief is pediocratic, the circulation of the winds would be more regular, and the precipitation diminished, at least at higher latitudes, and accordingly the loss of heat less. Besides, the air holds more vapour and has a greater capacity to retard the radiation into space.

4. The principal importance of the orocratic relief in producing

a miothermic state is, however, that the lofty parts of the land reach up into colder layers of the atmosphere, where they will be covered with perennial snow and ice. The more numerous, the higher and vaster the elevated tracts are, the more extensive the glaciated areas of the continents. And all the circumstances enumerated above which follow with orocratic relief, co-operate to lower the snow-line and thus to widen these areas.

The ice-caps, when once formed, and the annual snowfields of longer or shorter duration, have furthered the evolution of the miothermic climate. Insolation, reflection, and radiation take place on snowfields in such a way that the heat from the sun is only used to a slight degree for raising the temperature. Great masses of snow remain unmelted. The melting of the rest consumes a large part of the heat of the warm season, not only the insolation within the area itself, but in addition a considerable supply from the environs. Thus, the snowfields and ice-caps cause a lowering of the temperature outside their boundaries, and the cold water from them runs far beyond the ends of the glaciers and deprives the neighbourhood of heat.

5. More than other glacial regions, lands at high latitudes are responsible for the establishment of pronounced miothermic conditions. If there only exist high enough islands and continents, ice-caps will appear, extend their glaciers down to the sea, and send out their armadas of icebergs. To melt them, enormous quantities of the heat-reserve of the sea will be consumed. Cold water forms extensive superficial layers, and gradually fills the depth of the ocean right to the equator.

6. The greater the ice-caps grow, the more ice is bound in them which otherwise would run as water back to the sea. Consequently, its surface falls. Tylor [1] drew attention to this as early as the year 1868, and since then it has been discussed by many scientists. Nansen [2] has lately treated the question in detail. According to him, the surface of the sea would rise one metre, if the now existing glaciated areas were melted to an average depth of 24 m., and at the maximum of the Quaternary glaciation (altogether 50 million km^2., average thickness 1,000 m.), the land-ice contained so much water that the sea may have been at least 130 m. shallower than it is to-day. Nansen has made in his calculations very moderate assumptions of the extension and thickness of the ice-caps. Double the supposed thickness and more does not seem to be improbable. As we see, there must have been considerable changes of the sea-level by this cause, and it is obvious, that with such a sinking of the sea, the snow-line and the glaciers also must have moved downwards.

[1] Alfred Tylor, "Evidence and Cause of great changes of the Sea-level during the Glacial Period": GEOL. MAG., Vol. V, 1868, p. 576.
[2] Loc. cit., pp. 229–38.

Thus, miothermic conditions and ice ages are established as a consequence of orocratic relief.

If we now imagine the relief pediocratic, we shall find not only that the conditions producing glaciation and miothermic climate no longer exist, but also that the climate must have been pliothermic, much warmer than at present.

Even in the Arctic regions, the snow-line lies at considerable heights above the sea-level. This was the original condition also on the Antarctic continent, where the now existing snow-line at the sea-level has resulted from the active cooling effect of the huge glaciated land and the passivity of the cooled sea. This proves that, when the continents are peneplained, as assumed, they in no place reach up to so high a level that perennial snow could be formed and ice-caps cover them. The disadvantageous effect which glaciation has on the climate, fails. Heat is not taken from the atmosphere to melt ice, nor from the hydrosphere, for there are no longer any icebergs in the sea. Cold water does not extend over the surface of the sea at high latitudes, and the cold water in the depths receives no addition, but the oceans are gradually heated to ever greater depth, and the surface layer of warm water grows thicker and warmer. The sea-currents and winds bring more heat from the low latitudes to the polar regions, where the heated sea remains unfrozen and the climate becomes genial. If we further consider the regular circulation of the winds, disturbed by no mountains or elevations, and the augmented selective absorption of the atmosphere, we shall understand the conditions which led to the pliothermic climates, of which the fossils and sediments give evidence.

We need not look for any other cause of the great changes of climate during past periods or of the ice ages, than the changes of relief which the continents have undergone.

II.

It is also generally admitted that a mountainous relief is an essential condition of glaciation. But against the assumption that orocratic relief is the *cause* of ice ages, it has been argued that the relief has not shifted during the Quaternary period in a manner corresponding to the great differences in the climate of the ice age and recent times and of the repeated glacial ages and inter-glacial ages. And consequently, as change of relief cannot be the cause of the Quaternary alternations of climate, the actual cause of them, when once found, may also prove to include a better explanation of the greater climatic changes than the relief hypothesis. This objection does not destroy the theory.

For, if a miothermic climate is established—owing to an orocratic relief, as I think, or to other causes—it will for a long time oscillate between severer and milder conditions, before a certain equilibrium

is reached. Paschinger [1] has recently tried to show that the influence exercised by glaciation itself upon the level of "the zone of maximal precipitation" and on its own growth and decay, brings with it cyclic variations great enough to lead to glacial and interglacial stages. Certainly those meteorologic factors help to enhance and diminish glaciation, but it seems that the repeated accumulation and dissolution of the ice-caps is due to alternating elevations and depressions of the glaciated regions.

This was suggested by Upham,[2] referring to Jamieson's[3] assumptions that the regions had sunk under the load of the ice-caps and been raised by the removal of this load. Meanwhile, he combined with his theory features from the astronomic explanations of the ice ages, and, further, thought that subsidence of one region caused uplift of other portions of the earth's crust; so that glacial conditions may have prevailed alternately in the northern and southern hemispheres, or in North America and Europe. But there are weighty reasons enough for assuming a simultaneous appearance, not only of the glaciations on the northern and southern hemispheres, but also of the successive Quaternary ice ages in different quarters of the world.

The supposition that the dissolution of the ice-caps resulted from the depression of the regions under the load of the ice, has, however, been considered fallacious.[4] The depression being, namely at isostatic equilibrium only about one-third of the thickness of the ice, the surface of an ice-covered region is always more elevated than the region was before its glaciation. Consequently, the ice-cap does not disappear. Such a reasoning is right, if one has in view only the isostatic depression. But here come the changes of sea-level, too, as we shall see.

At the beginning of the Quaternary period the continents had orocratic relief, as at the beginning of the earlier miothermic ages. Their higher parts became glaciated, the ice-caps grew bigger, as described above, the sea was chilled, and the climate deteriorated. Enormous quantities of water being confined in the land ice, the sea-level and with it the snow-line sank. The icefields grew still larger, until they extended to so low levels or latitudes that the heat of the summer stopped them at a certain maximum. However, an equilibrium between glaciation and melting did not yet come about.

[1] V. Paschinger, "Die Eiszeit ein meteorologischer Zyklus": *Zeitschrift für Gletscherkunde*, xiii, Leipzig, 1923, pp. 29–65.

[2] Warren Upham, *Probable Causes of Glaciation*. In G. F. Wright, *The Ice Age in North America*, London, 1890, Appendix, pp. 573–95. "Pleistocene Climatic Changes": GEOL. MAG., 1894, pp. 340–9.

[3] T. F. Jamieson, "On the History of last Geological Changes in Scotland": *Quart. Journ. Geol. Soc.*, xxi, London, 1865. "On the Causes of Depression and Re-elevation of Land during the Glacial Period": GEOL. MAG., 1882, pp. 400–7 and 457–66. "On some Changes of Level during the Glacial Period and their causes": GEOL. MAG., 1887, pp. 344–9.

[4] R. D. Salisbury, Editorial Note: *Journal of Geology*, ii, Chicago, 1894, pp. 222–4.

For as the ice-caps got bigger and thicker, they loaded more and more the areas occupied by them. The crust of the earth gave way and began to sink, but not in the same proportion as the ice-load increased. The depression certainly reached its greatest depth only after, and long after, the maximum of glaciation, just as in the contrary case, the upheaval of Fenno-Scandia and other formerly glaciated regions has continued long after their release from the weight of the ice, and still continues.

As the depression proceeded, the ice-covered regions came gradually into lower positions in relation to the levels of the snow and glacier-lines for maximum glaciation. The ablation now gained upon the advance of the glaciers, the ice-masses began to diminish. The addition of water to the sea raised its level, and thus also the snow-line. This accelerated the melting of the ice, the sea-level rose steadily and so on. The more the sea-level rose, the better the warm sea-currents could pass over submarine thresholds and penetrate to higher latitudes. All this worked together to lessen glaciation and hastened the amelioration of the climate.

Meanwhile, as the weight of the ice-caps diminished to correspond to the depression of the ice-loaded area (i.e. as the average thickness of the ice was about three times the amount of the depression), the crustal sinking had reached its maximum and reversed in upheaval. But the dissolution of the ice, once begun, continued because the steady addition of water to the sea raised the snow-line. In the race between the upheaval and the rising of the sea-level, the latter won. When delivered from ice, the just glaciated regions were still deeply submerged. The velocity of the upheaval was certainly for some time greater than that of the rising sea-level, as proved by raised beaches (marine limits) and glaci-fluvial deltas from the late-glacial epochs. But the beaches formed at the maximum glaciation, when the sea's surface lay several hundred metres lower than now, and other portions of the geoid at this sea-level, have generally rested beneath the present sea-level, or perhaps above it only in the most upheaved parts of the regions in question. Further, the snow-line may have risen more than the sea-level in consequence of the amelioration of the climate by the decrease of the glaciation. The melting, the rising of the snow-line, and the general improvement of the climate proceeded rather in an accelerated degree, on analogy with the case in late-glacial time in Fenno-Scandia investigated by De Geer [1] and Sauramo.[2] Finally an interglacial stage with restricted glaciation and genial climate appeared.

[1] Gerard De Geer, "A Geochronology of the last 12,000 years": *Compte rendu du XI Congrès Geologique Internationale*, Stockholm, 1910, pp. 241–53. "A Thermographical Record of the late-Quaternary Climate": *Die Veränderungen des Klimas seit dem Maximum der letzten Eiszeit* (*Congrès Géol. Intern.*, 1910), Stockholm, 1910, pp. 303–10.

[2] Matti Sauramo, "Studies on the Quaternary Varve Sediments in Southern Finland": *Bulletin de la Commission Géologique de Finlande*, No. 60, Helsingfors, 1923.

But the loftier portions of the regions were gradually raised anew above the snow-line and glaciated. All the consequences of this pointed out in the foregoing pages led to a new general ice age, again followed by an interglacial stage and so on.

Above, the rise of the sea-floor by subsidence of ice-covered land is omitted, as also the reverse events. If considered, they should accent the supposed effect of crustal movements on growth and decline of the ice-caps.

The cause of these oscillations (Fig. 1) between severer and milder miothermic climate is, then, that the land movements due to the increasing and decreasing of the ice-caps have their maxima and minima at other points of time than the variations of the ice-caps and of the sea-level (snow-line). In the course of time the amplitudes of the successive oscillations must decrease until a balance in the miothermic climate is attained; moderate glaciation with isostatic

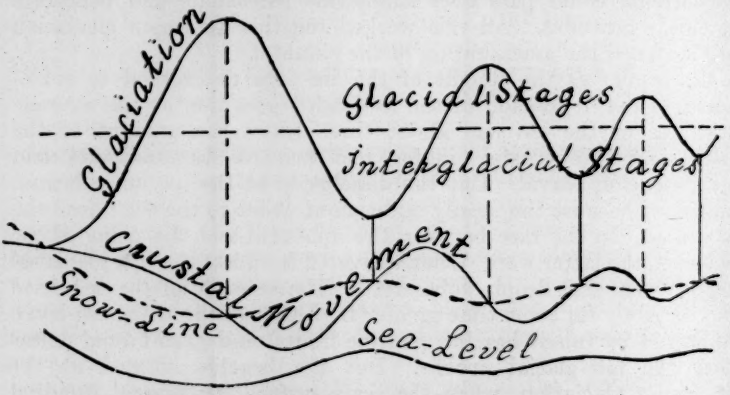

FIG. 1.—A schematic sketch illustrating the relations of glaciation, crustal movement, and oscillation of sea-level.

equilibrium between depression and ice-load, cessation of upheaval or submergence of the formerly glaciated lands. We are not yet at that point. I think, with Nansen,[1] that the last post-glacial transgression of the sea in Fenno-Scandia indicates the maximum of dissolution of the ice-caps and the highest position of the sea-level. The climate then was most favourable and has since declined.

In the diagrammatic presentation of the alternation of glacial and interglacial stages, it is not to be supposed that this proceeds in just the same way in different regions. Their varying size and altitude makes it probable that their maxima and minima of glaciation or upheaval and sinking will not absolutely coincide, and the glaciation of different regions not be of equal duration. Further, their geographical situation can in many ways alter the influence of cold or hot sea-currents, winds and other agencies. Notwithstanding,

[1] Loc. cit., pp. 286–7.

the changes of climate must on the whole correspond in the different regions all over the globe, regulated as they are by the general chilling and heating of the oceans and by the general sinking and rising of the sea-level.

The theory here proposed contains a general thesis: that the alternating pliothermic and miothermic conditions depend upon changes between pediocratic and orocratic relief, and a special thesis that the succession of glacial and interglacial ages during a miothermic period depends upon isostatic and eustatic oscillations of level. The theory thus sees the causes of the different climates during past eras in different geographical circumstances. Attempts to solve the puzzling question from this point of view were made almost a hundred years ago, and have never been abandoned. One by one, the facts and ideas on which the above theory is founded have been put forward, and with the increase of our geological knowledge they have grown ever clearer and more convincing. I believe, therefore, that the relief theory will be approved as the true solution of the climatologic problem in geology, though it may be only after discussion and improvement.

The Unconformable Base of the Coniston Limestone Series in the Lake District.

By Bernard Smith, M.A., F.G.S.

DURING the course of a recent excursion of the Cambridge Sedgwick Club to the Coniston District, under the guidance of Professor J. E. Marr, important evidence was obtained upon the relationship of the Coniston Limestone Series to the Borrowdale Volcanic Series. A visit was paid to the area south-west of Torver Beck, when, after Professor Marr had pointed out the marked difference between the strike of the Coniston Limestone and that of the underlying Borrowdale rocks at High Pike Haw,[1] the actual strongly discordant junction was located by Professor O. T. Jones and the writer. This was found to be one of unconformity and not a fault, and was traced by the party for some distance.

It is not the intention of the present writer to describe this unconformity, but notice may be drawn to the fact that beneath the Limestone proper there is a variable thickness of beds composed largely of volcanic material, including undoubted conglomerates and breccias, and also finer sediments, probably derived from the waste of volcanic rocks; and that parts of the series contain fossils.[2] Professor O. T. Jones and Mr. T. C. Nicholas, who also examined the junction, now propose to study it in detail.

[1] Marr, *Geology of the Lake District*, p. 37 and fig. 7.

[2] A calcareous ash with fossils, "The Style End Grassing Beds," was discovered years ago by Professors Harkness and Nicholson in the eastern part of the Lake District. It was also recognized by them near Millom (*Quart. Journ. Geol. Soc.*, vol. xxxiii, 1877, p. 461).

The varying opinions that have been expressed by workers in the Lake District upon the relationship of the Limestone Series to the Borrowdale Volcanics have been expounded by Mr. J. F. N. Green,[1] who himself has claimed that the two series are unconformable. His investigations [2] confirm to a great extent, as well as amplify, the earlier official work of Aveline in particular, and De Rance, in establishing this relationship throughout the south-eastern part of the Lake District, and opportunity was taken to make this apparent in the course of a lecture to the Geological Society in March, 1918. Clifton Ward appears to have held the same views, and J. D. Kendall was of the opinion that the Limestone was unconformable in the Ireleth District.

Professor Marr [3] quotes De Rance as saying [4] "that in tracing the outcrop of the Coniston Limestone across country, it was found to rest upon different members of the underlying volcanic series, which plunge under it with varying direction of strike and amount of dip, the unconformity being so marked between the two sets of rocks that occasionally the volcanic series appear to have obtained a dip, been denuded, and faulted before the deposition of the overlying Coniston series".

Aveline [5] described the break in the sequence in 1872, and restated his views in the Memoir on Quarter Sheet 98 N.E. (New Series 39) as follows [6]: "Observations in the field show that the Coniston Limestone Series, west of Coniston, is lying on far lower beds of the Borrowdale Series than at Shap. There is a far greater discordance than can be accounted for by any local disturbance. I regard the volcanic rocks that were ejected during the deposition of the Coniston Limestone Series as of much later date than those of the Borrowdale Series."

Although, however (in addition to the above remarks), these Surveyors recorded their observations upon the 6 in. maps of the Geological Survey, and, more especially, upon the published sheets of Horizontal Sections, the non-appearance of a memoir upon the main Coniston District seems to have left doubts in the minds of many as to whether the interpretation shown upon the maps and in the sections was based upon facts that could be well authenticated.

There appears to be no doubt that the unconformity is con-

[1] "The Structure of the Eastern Part of the Lake District," *Proc. Geol. Assoc.*, 1915, pp. 196–201.

[2] *Op. cit.*, pp. 216–18; and *The Older Palæozoic Succession of the Duddon Estuary* (privately printed), 1913, pp. 17–21.

[3] *The Geology of the Lake District*, 1916, p. 35.

[4] In discussion of a paper by Harkness and Nicholson, "On the strata between the Borrowdale Series and the Coniston Flags": *Quart. Journ. Geol. Soc.*, vol. xxxiii, 1877, p. 483.

[5] "On the Continuity and Breaks between the various Divisions of the Silurian Strata in the Lake District," GEOL. MAG., 1872, p. 44.

[6] "Geology of the Country around Kendal, Sedbergh, Bowness, and Tebay": *Mem. Geol. Surv.*, 1888, p. 8.

siderable, and of more than local value; hence it seems advisable to publish some of the evidence upon which it was first established.

The following short passages are taken, with the permission of the Director of the Geological Survey, from Aveline's unpublished notes[1] assembled for a memoir upon Sheets 99 N.W. and 99 N.E.

I. Notes on the Borrowdale Series.

On the Yewdale Breccia: "The Yewdale Breccia is very high up in the Volcanic Series, probably the highest in the district in the neighbourhood of Coniston; it is immediately overlain by the Coniston Limestone Series, which overlaps it between 2 and 3 miles south-west of Coniston."

"Underlying the Yewdale Breccia and dividing it from the slaty ashes below, is a coarse breccia which is traceable from the Yewdale Beck south-westward to where it is overlapped by the Coniston Limestone, 2½ miles to the south-west of Church Beck, Coniston."

On a lava (?) at a lower horizon: "On the south side of our district to the west of Apple-tree Worth there is a large mass of rock which has puzzled me much as to what to class it with . . . It may be seen that the Coniston Limestone lies on it on the south-east side, passing from the volcanic ash beds on to it . . . This, then, will be the same bed that commences at Stanton Ground (and) passing between Dry Hall and Ball Hall, goes beneath the Coniston Limestone at Carter Ground Wood."

On the Tilberthwaite, Coniston, and Walney Scar Slate Belt: "From Walney Scar the belt of cleaved ashes bends southward and strikes towards the Coniston Limestone, by which formation they are finally overlapped."

II. Notes on the Coniston Limestone Series.

Introduction to Coniston Limestone Series: "The Series consists of beds of bluish or grey limestone generally of a concretionary structure and very fossiliferous, the lower beds are often ashy in character, and sometimes a breccia forms the base."

"There is also a general bend in the Volcanic Rocks on the western side of the district towards the south, with a dip to the east, which is not the case in the higher (i.e. Coniston Limestone) beds."

On the Coniston Limestone Series: "It is at the base of the limestone beds at the eastern side of Limestone Beck that ashy beds were first noticed containing fossils, and were supposed by Professor Harkness to belong to the Volcanic Series, but I consider them as a fine ashy sandy base to the Coniston Limestone Series, the same as described in the explanation of (Sheet) 98 N.E., occurring at the base of the Coniston Limestone between Kentmere and Longsleddale; also the same as the beds occurring west of Coniston, which will be again alluded to" (next par.).

[1] Edited, but no words or sentences altered. (Approx. date 1877–82.)

"On the north-east side of Torver Beck fossiliferous ashy beds are again found at the base of the Coniston Limestone; they are of no great thickness, and here they clearly lie unconformably on the main volcanic series, and quite conformable to the overlying limestone. In the Torver Beck there is, what appears to me, a conglomeratic breccia, which I believe belongs to the Coniston Limestone Series, though there may be a little uncertainty about it; but there is no doubt that breccia forms the base of the Coniston Limestone a little to the south-west of Torver Beck."

The following section is given of the beds, in upward succession, at this locality:—

(*a*) Volcanic Series. (*b*) Brecciated conglomerate, 0–100 ft. (*c*) Concretionary limestone, 250 ft. (*d*) Ashy sandstone, 25 ft. (*e*)[1] Blue fossiliferous slate, 50 ft. (*f*) Dark mudstones. (*g*) Pale-coloured beds. (*h*) Coniston flags.

(*b*), (*c*), (*d*), and (*e*)[1] constitute the Coniston Limestone Series, of a total thickness of 425 feet.

"The basement conglomerate, (*b*), which lies unconformably on the Volcanic Series, is a purplish coloured rock rather of an ashy nature in the composition of its matrix, containing well water-worn pebbles. It can be traced, lying below the limestone, for over a mile. It is too thin to be shown on the 1 in. map, but has been laid down on the 6 in. map" [No. 4 Lancs.].

Extracts might be given also of detailed descriptions of the horizontal sections crossing the unconformity—particularly Sheet 113 (Nos. 1 and 2) and Sheet 114—but they are drawn so clearly that little description is necessary. The section, Sheet 114, crosses the unconformity at a point where dip and strike of the two series are somewhat similar. The break, therefore, is not shown prominently; it is, however, as stated above, strikingly pronounced when studied closely in the field.

Summing up the evidence quoted above, it appears that the unconformity received the attention of the Surveyors to a great extent, and might have gained widespread recognition at an early date had publication not been suspended.

Before leaving the subject it may be well to set out other views evidently held by Aveline:—

(i) He interprets the absence in places of "Ashgill Shales" and parts of the Coniston Limestone Series as probably being due to overlap, although strike faulting also undoubtedly occurs. He states definitely (MSS. description of Hor. Sect. Sheet 114): "they [Stockdale Shales] do now and again gently transgress on to the lower, and it is possible that the higher beds of the Coniston Limestone Series, missing here, namely the Ashgill Slates, and the 'ashy-sandstone bed', may be overlapped".

(ii) He considered that the Volcanic Slates of Coniston Old Man

[1] Described by Professor Marr as "Ashgill Shales", since the above section was first drafted; *Quart. Journ. Geol. Soc.*, vol. xxxiv, 1878, pp. 873–6.

overlap and cut out the underlying hornstones and hard breccias, "the transgression of the higher beds of the volcanic series on lower."

(iii) The outcrop of the Coniston Limestone is in places shifted southward by transverse faults which apparently have not affected the outcrops of still higher horizons (higher Coniston Grits and Flags). This Aveline explains as due to the accommodating compression and buckling, between the transverse faults, of the beds above the Limestone Series and below the unaffected outcrops of Coniston Grit, etc.

The Facies Classification of Metamorphic Rocks.

By C. E. Tilley.

THE diversity in mineral composition of metamorphic rocks can be regarded as the resultant of two independent variables, first of the ultimate composition of the rocks, and secondly of the grade of metamorphism, or the particular pressure-temperature conditions under which the rocks have arisen. It is clear that these two variables may well form the basis of a classification of rocks of metamorphic origin.

In Grubenmann's well-known classification of the crystalline schists [1] these two variables occupy the dominant positions, and are the foundation upon which his classification is erected. Thus the twelve groups adopted by Grubenmann represent the composition-variable, and his three-fold division of depth zones—epi, meso, and kata—is an attempt to express the variation induced by the imposition of varying physical environment, in other words the grade.

Whatever may be said of the chemical part of Grubenmann's classification, there can be few who would regard the division into three zones as satisfactory or at all adequate to express the diversity of rock types brought about by their subjection to varying grades of metamorphism. Moreover, Grubenmann has no well-defined place for rocks which have arisen under the conditions prevailing in contact metamorphism, and for any classification to be adequate, such rock types cannot be ignored.

In a recent paper Eskola [2] has attempted to surmount some of the obvious difficulties which are associated with the classification of Grubenmann.

Rocks are grouped into "facies" corresponding in kind to the depth zones of Grubenmann, but greater in number. The term "metamorphic facies" is defined "to designate a group of rocks characterized by a definite set of minerals, which under the conditions obtaining during their formation were in perfect equilibrium with each other. The quantitative and qualitative mineral com-

[1] Grubenmann, *Die Kristallinen Schiefer*, 1910.
[2] *Norsk. Geol. Tidsskr.*, vi, 1920, pp. 143–94.

position in the rocks of a given facies varies gradually in correspondence with variation in the chemical composition of the rocks".

Thus in this scheme a given facies may include rocks of widely different bulk-composition, the variable of chemical composition is thus allowed for, whilst the number of facies expresses the variable physical environment under which the rocks have been formed. This conception is a distinct advance over the classification adopted by Grubenmann, and one is impressed with the elasticity of the classification, for the number of so-called facies may be indefinitely increased as progress in the study of metamorphism may require.

The term "facies" as applied by Eskola must be considered as somewhat unfortunate, as Becke [1] has already pointed out. Facies is a term long since established in geology, but its use is now bewilderingly lax. It has been adopted in palæontology, but is also used in tectonics and stratigraphy. Petrology has not escaped, the term being used with reference to a variant of a rock type, as in "marginal facies", etc. If no other term be suitable for the rock groups of Eskola, it is to be hoped that the word will henceforward be used petrologically only in this definite sense.

The metamorphic facies already set down by Eskola are the following: Hornfels facies, Sanidinite facies, Green schist facies, Amphibolite facies, and Eclogite facies. These form the basis upon which other facies will be constructed. The nomenclature of the facies, however, will not reach finality at this stage, owing to lack of the requisite data. It appears to the writer that the prefix attached to individual facies will be that of the mineral assemblage most susceptible to mineral change under a given change in physical environment, and which rock types possess this property in the highest degree is a problem for the future. Only in this way can the maximum necessary number of facies or facies-groups be established. In connexion with the conception of facies, that of grade should be associated. Grade is a term already established in metamorphic petrology to signify the degree or state of metamorphism. Thus we may speak of a low-grade facies or a high-grade facies, represented for example by the green schist facies and eclogite facies respectively.

Rocks which belong to the same facies can be said to be in the same *metamorphic grade*, and can be referred to by the terms which I now suggest as *isofacial* or *isogradic*. *Isograde* rocks are those which have originated under closely similar physical conditions of temperature and pressure. This term will be of use in comparing the rocks of varying composition, which occur close together in a region of progressive metamorphism, and have thus arisen under the same P.T. conditions. Thus a chlorite-muscovite-quartz-schist is isogradic with a green schist composed

[1] *T.M.P.M.*, xxxv, 1921, p. 215.

of chlorite, epidote, and albite. They both belong to the green schist facies. It has been stated above that in prefixing the particular facies, a common assemblage, the most susceptible to mineralogical change, should be selected, so that the maximum necessary number of facies may be established. This might be illustrated by the rock types referred to above. A chlorite-muscovite-quartz-schist is stable over a greater range of P.T. conditions than the corresponding green schist type. Thus among the Green Beds of the Dalradian series, the entry of hornblende into rocks of this type takes place earlier, as metamorphism progresses, than the incoming of biotite in the argillaceous rocks.[1] It is necessary therefore to derive a second facies characterized by hornblende, epidote, and albite or oligoclase, of which the chlorite-muscovite-quartz-schist is also a member. This facies has not been recognized by Eskola, but its existence has been pointed out by Becke in the paper already cited. The writer has met it not only in the Highlands, but also in the metamorphosed rocks of the Start area. It is a facies of widespread distribution. By selecting one type of sediment Barrow has been able to map zonally the metamorphic region of the south-east Highlands and his published map is the most detailed and complete of any metamorphic area yet subjected to zoning.

The succession of zones is given by the entry of a particular mineral; in the argillaceous rocks selected by Barrow, the succession is given by the index minerals, chlorite (= zone of digested clastic micas), biotite, garnet, staurolite, kyanite, and sillimanite. Along the line joining the points of entry of biotite in rocks of the same composition, the rocks, whatever their composition, may be said to be in the same metamorphic grade, and have recrystallized under the P.T. conditions leading to the production of biotite in the particular rocks.

In the terminology suggested above, this line may be said to be an *Isograd*. This term may be used in the same sense as isotherm or isobar. It may be thus defined as a line joining points of similar P.T. values, under which the rocks as now constituted, originated. In reality an isograd is the intersection of an inclined *isograd surface* with the earth's surface. So we may speak of a biotite isograd, garnet isograd, etc., when referred to a given rock type. One of the most important objects in a study of progressive metamorphism is the elucidation of equivalent grades of metamorphism in a series of mixed sediments. Expressed in facies-petrology, this reduces to finding the set of minerals which belong to one and the same facies, or the determination of isogradic rocks. From the results accruing from such a study, we should be enabled to insert additional isograds to fill the gaps between the present ones established by Barrow. As has been noted, one rock type may be a member of more than one facies. In beds of green schist composition a hornblende isograd

[1] Green Beds of a definite and limited range of chemical composition are here referred to.

must be inserted below the biotite isograd of the pelitic sediment. It is perhaps not too much to hope that in the future—distant though it be—these empirical isograds may be given approximate quantitative P.T. values.

Thus far it has been implicitly assumed that the various rock types or mineral assemblages which unitedly make up a metamorphic facies are in chemical equilibrium. A departure from equilibrium in nature, however, is not uncommon, more frequent indeed than Eskola would appear to recognize. Becke, in his criticism of the facies classification, has laid stress upon this aspect of the question, and cited examples of non-equilibrium rocks. It would not be difficult to add further examples to his list. Any mineral assemblages in which one mineral is in process of arising from another must be regarded as being in unstable equilibrium. It is not solely a question of relict minerals being armoured by reaction products, but often a case of incomplete reaction with the assemblage still within a common sphere of diffusion. Rocks formed under given P.T. conditions tend to undergo mineral reaction when these conditions are changed, as on a cooling curve, which reaction may be complete or only partial.

That we are now able to study rocks which have originated under high-grade metamorphic conditions, as Harker has pointed out, is due to the fact that the lag effect during cooling of the rock is much greater than the lag accompanying rise of temperature. Rocks whose mineral assemblage was originally that of a high-grade type, when subjected to progressive metamorphism, accommodate themselves to changing P.T. conditions much less readily than rocks originally composed of degradation minerals. This state of affairs can be well illustrated by the Green Beds and epidiorites of the southern Highlands. Both these rocks have been subject near the Highland Border to a metamorphism of a low-grade type. In its low-grade condition the Green Bed is constituted of chlorite, epidote, and albite. The metamorphosed epidiorite which accompanies it is, however, characterized by hornblende, epidote, and albite. Both rocks are essentially of the same chemical composition, but the Green Bed has accommodated its mineral composition to the impetus of rising temperature, while in the case of the epidiorite, the original assemblage was of a high-grade facies (igneous rock), the reaction has been incomplete, and it is only partially converted to the chlorite-epidote-albite assemblage.

The foregoing and kindred considerations that follow in their train must certainly imply that natural rocks can only be fitted into and accommodated in a classification of the facies type in a rough approximate fashion; nevertheless, one is led to believe that provided the limitations imposed by the non-attainment of equilibrium are clearly admitted and recognized, the facies conception in metamorphic petrology will serve as a very useful guide to aid us on the way towards the goal of deeper understanding of metamorphic processes.

Conclusion.

(1) In the use of the facies classification of metamorphic rocks due regard must be given to its limitations, more particularly with reference to those rocks which are in a state of incomplete equilibrium, whether these be rocks of the outer zones of contact aureoles, where recrystallization is incomplete, or recrystallized rocks of any grade of metamorphism.

(2) The present nomenclature of individual facies must be tentative only. The mineral assemblage most susceptible to change under varying P.T. conditions should be adopted in the naming of individual facies groups, and it is preferable that this prefix should be mineralogical rather than that of a rock type.

(3) The conception of grade in metamorphism is here discussed, in the light of the facies petrology, and the terms *isograde* and *isograd* introduced and defined. These should be of service in the study of areas of progressive metamorphism, such as the Scottish Highlands, or the Caledonian chain of Scandinavia. From the detailed examination of such regions, the most important advances in metamorphism should result, and the data for the development and extension of the facies conception be provided.

REVIEWS.

Fossil Men, Elements of Human Palæontology. By Marcellin Boule. Translated from the French by Jessie Elliot Ritchie and James Ritchie. Edinburgh, 1923. 36*s*.

ENGLISH readers will welcome this work of the distinguished palæontologist who, uniting a remarkably full and exact knowledge with an equally remarkable power of vivid representation, has produced on this recondite subject a book which is indeed a book and not a Bradshaw. But this is only what we might naturally expect from the pen which has given us such a masterly monograph on the skull, and not only the skull, but the whole skeleton of that extinct species of man, *Homo neandertalensis*. The translation is worthy of the original: it not only reproduces the lucidity and precision which are the common possession of all French writers, but preserves the dignity and grace which are personal to the few.

The book opens with an historical summary; a story full of very human interest, centring around the eternal struggle between the conservative and revolutionary forces, which so often attends the progress of discovery. The great protagonists are Cuvier and Boucher des Perthes, and our sympathies are engaged on both sides. The tale is well told, and is especially interesting since it is the first presentation in the English tongue of this subject from the French point of view.

A chapter follows on geological chronology. Here we imagine the thickness of the Secondary and Tertiary deposits are rather

under than over estimated. The lower Palæolithic age is restricted to the Riss-Wurm inter-glacial episode. This may be well so, but some reference might fairly be made to the large and increasing number of investigators who would extend it into the Mindel-Riss.

Then comes a chapter on the Primates. This gives just the kind of information which is necessary to prepare the mind of

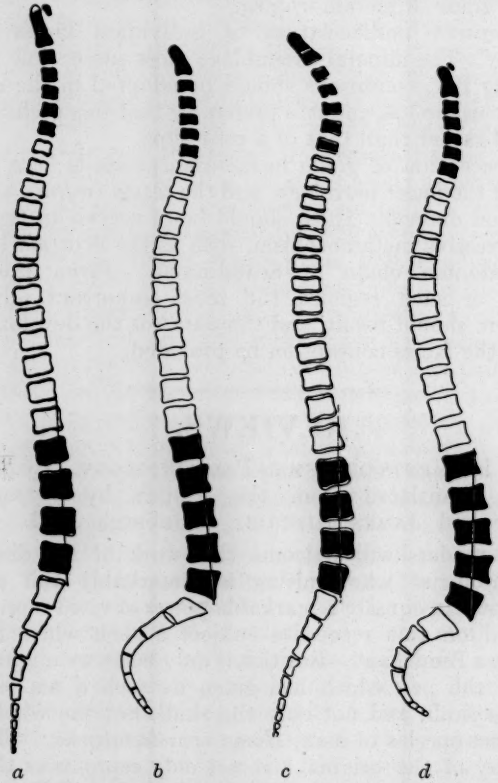

FIG. 1.—Sections of the vertebral column of man and the chimpanzee to illustrate the resemblance of the cervical and lumbar curvature in each. *a*, *Troglodytes niger*, male; *b*, man; *c*, *T. niger*, female; *d*, man. The great difference lies in the sacral curvature. (After D. J. Cunningham.)

the lay reader for the serious study that awaits him. The expert will probably renew his acquaintance with Cuvier's Bimana and Quadrimana with some surprise; the author's excuse is that these terms are useful for the work he has in hand. A matter of more importance is the statement that the spinal column of the higher apes is distinguished from that of man by the absence of a lumbar curvature. This is an error consecrated by the observations of many great naturalists, but even as far back as the middle of the

last century (1863) Huxley was able to assert that all the curves of the human spinal column are to be found in the gorilla and the chimpanzee, and the matter was finally placed beyond the possibility of doubt by D. J. Cunningham (1886), whose observations made on sagittal sections taken through the frozen bodies of the chimpanzee, orang, and other apes, showed that in the chimpanzee the lumbar curve is as well marked as in man himself, and the cervical curve is present, though less pronounced. Cunningham also concluded, but from observations of another kind, that in the gorilla the lumbar curvature exceeds that in man.

The chapter on *Pithecanthropus* is a model of clear exposition: but it is difficult to know in what sense we are to interpret the statement that sutures are no longer visible in the skull cap; the bregma, at least, has been observed both by Dubois and Manouvrier.

On the vexed question of eoliths the author stedfastly maintains his original attitude of negation, but records, rather sadly, the admissions of Professor Breuil. The problem is still unsolved, and so difficult that it perhaps never will be solved. We notice in passing that Nœtling is cited as an English geologist, but he was certainly a German when in charge of the Museum of the Geological Survey of India: he is now probably a Tasmanian.

The Piltdown skull is fully and fairly discussed; originally denounced by the author as a monster compounded of a man's skull and an ape's jaw, it is now regarded less positively as in a doubtful case calling for suspension of judgement. The masterly chapter on Neandertal man will prove as invaluable to the student as it is interesting to the general reader. The only criticism we have to offer relates to fig. 119, which is said to represent the relative capacity of a series of skulls by sagittal sections superposed on a common base. This, however, does not take into account differences of width, and the difference in this dimension between the French skull and the Neandertal is very considerable, the Neandertal being much the wider.

Not less instructive is the chapter on the remains of the men of the reindeer age, and all who share the author's views on the relation of magic to the art of this period will welcome his remarks on p. 257: "The truthfulness of the drawings, the purity of the lines, the grace of the attitudes, cannot be accounted for by the simple practices of magic."

In discussing the relationship of the Palæolithic to the Bushman art, Peringuey is quoted as attributing the latter to a people he calls "Strandloopers", but these, as Dr. Broom has shown, are not a race at all: some of them were Hottentots but the greater part were Bushmen. The statement that no one has seen the Bushmen in the act of making drawings must surely rest on a misconception, for Dr. Hahn, in 1879, asserted that it was a common practice among the Annin in the Orange district, and that the old people taught the children how to draw.

The survey of the relations of the fossil men to existing races is treated with unusual fullness, and is not the least interesting chapter in the book which concludes with an account of fossil men beyond Europe and a chapter of general conclusions.

I have read it with unalloyed pleasure, and it has been a pleasure to exercise myself in a friendly criticism for which the occasion has too seldom been presented. Those who are tired of paradox and the wild fantasies of much that is written under the name of anthropology, "the brilliant contradictions of Klaatsch and the pedestrian incongruences of Schliz", not to mention others, may here find a refuge where they will meet with logical presentment, sound judgement, and unfailing moderation. After some others it is like escaping from a madhouse into the sunshine and the open air.

It is unfortunate that so excellent a production should be advertised by a misleading publisher's puff.

W. J. Sollas.

Memoirs of the Geological Survey of Scotland.

(1) Geology of Corrour and the Moor of Rannoch (Explanation Sheet 54). pp. i–iv, 1–96, figs. 1–6. Published H. M. Stationery Office. Price 4*s*.

(2) Geology of the Lower Findhorn and Lower Strath-Nairn (Explanation Sheet 84 and Part 994). pp. 1–128, figs. 1–3. Published H.M. Stationery Office. Price 5*s*.

(1) The district comprised within sheet 54 extends from Lochs Treig and Garry to Black Mount and the north slopes of Ben Lawers, the greater part of it falling within that area of desolation known as the Moor of Rannoch, occupied almost entirely by the Moor of Rannoch granite, which in Pleistocene times appears to have formed a centre of ice dispersal.

Geological interest centres chiefly on the chapters dealing with the Central Highland Schists, in which presumably we are given the latest information respecting the views held as to their structure and succession. There is not much that is new in the section dealing with the schists north-west of the Ericht-Laidon fault; the summaries given as to the views held regarding the structure of the Loch Treig area are already familiar from the work of Mr. Carruthers and Mr. Bailey in the area included in the explanation of sheet 53, of which this Loch Treig area forms the natural continuation. An important footnote, however, suggests that the use of the term Moines for any Central Highland Rocks does not meet with general acceptance, and must be considered open to question. In the section dealing with the schists south-east of the Ericht-Laidon fault there is much that is new and suggestive. The rocks are divided into four groups, (1) the Moine Series, (2) Schists of the area south of Gortan, (3) Schists of the Leagag, Cross Craigsand-Meall a Bhobur area, and (4) the Glen Lyon Series.

The Moine Series appear here to be mainly siliceous or semi-pelitic in character, and are very generally affected by regular isoclinal folding of the type familiar to all students of Highland geology from the fine sections exposed in the River Garry, but their regularity is interrupted in places by narrow belts of highly inclined folding, for which the expressive term "rucks" is used. Little can be said at present as to the structure or relations of group 2, but it is suggested that the schists of group 3 represent an isolated outlying portion of a recumbent fold of the Central Highland Schists. It is, however, respecting the Glen Lyon Series that most new information is supplied. Here the structural succession is given as follows :—

Blair Atholl Series.
Schichallion Quartzite.
Killiecrankie Series.
Glen Lyon Series { Pebbly Quartzite. / Black Schist. / Ben Lawers (calc-sericite) Schists. / Garnetiferous Mica Schists (with Loch Tay Limestone).

This division of the Perthshire quartzite into three, and the position of the Blair Atholl Series is due to the recent work of Mr. Bailey in the Pitlochry district, work clearly of great significance, the details of which are eagerly awaited. Very interesting also is the recognition that in Glen Lyon the Garnetiferous Mica Schists approach very nearly in type to flags undoubtedly belonging to the Moine Series.

Under the heading "Structural Relationships", the general view is expressed that the Moine Schists are the oldest rocks, and the surrounding schists are brought into different structural relationships by the combined effect of folding and thrusting. A guarded statement of this nature is probably wise at the present juncture, when, as is rightly said, the fullest comprehension of the structure cannot be gathered within the limits of the sheet here described. More is, however, hinted at; we are told, for instance, that whatever the interpretation finally adopted, it is expected that slides will be found to have played an important part; the rocks of the Ben Lawers Ridge are to be regarded as a structural syncline pitching north-east. This is true so far as it goes, but probably only represents a part of the truth, as does also the statement that overfolding accompanied by small scale thrusting plays an important part in the tectonics. Here, again, attention is perhaps focussed on the smaller rather than on the larger structures involved in the general whole.

The Moor of Rannoch Granite is considered to be part of a batholithic mass, with remnants of the sedimentary roof still preserved; originally it seems to have formed two masses—the Moor Mass and the Strath Ossian Mass, and it belongs to that section of the Newer Granites intruded after the cessation of the great regional movements but before the Cruachan Granite, which is

referred to the Old Red Sandstone. On its eastern margin the granite forms an interesting intrusive complex with the Moine Schists, the granite penetrating the schists in very intimate manner and containing numerous schist inclusions, many of which have been torn away from the main mass. As might be expected from the nature of the rocks into which the granite has for the most part been intruded, there is little evidence of thermal metamorphism, though where the Eilde Flags come within the aureole, andalusite hornfelses, which probably also contain cordierite, have been noted.

In the chapter dealing with the glaciation, mention is made of the occurrence of definite parallel roads or strand lines belonging to glacial Loch Tulla.

(2) The district described in the second of the Memoirs (2) comprises the Lower Findhorn and Lower Strath-Nairn, its west limit being taken on a line from Tomatin on the Findhorn to Inverness, together with a small part of the Black Isle near Fortrose and Rosemarkie, and the area of the Culbin and Maviston sandhills. The higher parts of the district are occupied by the rocks of the Moine Series, invaded by various granite masses of which those of Glenferness, Moy, and Park are demonstrably older than the Middle O.R.S. ; the lowland area is occupied by Middle and Upper O.R.S., the upper being confined to the south side of the Moray Firth.

The Moine Series consists of siliceous granulites and pelitic schists, all regarded as of sedimentary origin on account of their chemical composition and lithological characters ; petrographical details of these rocks are supplied by Dr. Flett, who comments on the scarcity of limestones, and suggests that they represent a great continental formation.

Two interpretations of the structural feature known as the " Streen Ring " of pelitic gneiss are offered, one of which involves recumbent folding, and is of interest in relation to the views held regarding structural features in other parts of Scotland.

The Igneous Rocks call for little comment beyond the fact that the Older Basic Rocks show a distinct departure from the more usual type of Garnetiferous Epidiorites or Hornblende-Schists.

The O.R.S. Rocks have long been known on account of their fish fauna, the nomenclature of which is now brought up to date by Dr. Traquair, and an interesting and valuable summary of the development of research on these rocks is contributed by Dr. Horne, in which the importance of the observations of many local workers, such as Dr. Malcolmson, is clearly indicated. The lower group, constituting the Middle O.R.S., is dealt with in the two areas, (1) south of the Moray Firth, and (2) north-west of the Moray Firth, this last being a continuation of the area already described (sheet 3). In the area south of the Moray Firth the beds are divided into five subhorizons, which is especially important when the relations of the Upper O.R.S. to the lower beds is considered, and allows its transgressive nature to be demonstrated clearly. It is suggested that the

lithological features shown by this Upper division are more in accordance with accumulation under continental conditions than in an inland lake.

A chapter of great interest is devoted to the glaciation, which seems to be divisible into three distinct stages, (1) a maximum period when the whole area was covered by ice moving outwards from high ground, situated to west and south in the counties of Ross and Inverness, (2) confluent glacial period when various glaciers coalesced on lower ground leaving the higher hills as "nunataks", and (3) valley glacier period when various glaciers retreated up the glens. Here, also, the nature of the evidence available respecting the disputed origin of the Clava Shelly Clay is summarized, whilst the fauna of this highly interesting deposit forms a suitable appendix.

G. L. E.

THE EVOLUTION OF CLIMATE. By C. E. P. BROOKS. pp. 173. London: Benn Brothers, 1922. Price 8*s*. 6*d*. net.

THE title of this book is not altogether appropriate. By far the greater part of it is devoted to the climate of the Quaternary period, and only fourteen pages are allotted to the rest of geological time. But, except that it is not suggested by the title, the limitation is no disadvantage. The interest of the book lies chiefly in its application of meteorological methods to geological problems, and in the earlier periods the data required by these methods are not available.

Mr. Brooks believes that the Ice Age was brought about by geographical changes, and that astronomical and other causes have had little effect. The theory is by no means new, but hitherto the way in which these changes act has only been vaguely indicated. Mr. Brooks endeavours to treat the question more precisely.

By an analysis of the existing distribution of temperature he has shown[1] that the present January or July temperature of any point (reduced to sea-level) can be approximately expressed by a simple formula. The terms of the formula depend upon the latitude, the amount of land in the western half of a circle of ten degrees radius drawn round the point as a centre, the amount of land in the eastern half of the same circle, and, in high latitudes, the amount of ice in the circle. A table in the appendix gives the figures required for the calculation. The principle upon which Mr. Brooks proceeds is that for small geographical changes these figures will still be sufficiently accurate, and consequently it is possible, in parts of Europe at least, to determine with some precision the temperatures of the different subdivisions of the Quaternary period.

It is to be regretted that he does not enter a little more fully

[1] *Quart. Journ. Met. Soc.*, 1917, p. 159, and 1918, p. 253. See also *ibid.*, 1921, p. 173.

into the matter, for from this table the reader is likely to obtain results which may shake his confidence. In the particular case given as an illustration of the great effect of geographical changes he will obtain temperatures very different from those in the book. In his original paper Mr. Brooks explains the discrepancy, but no such explanation is attempted here. Further, if the reader should have the curiosity to examine the figures for 70° N. Lat.—and such curiosity is naturally suggested by a mere inspection of the table—he will find that for a point in this latitude surrounded by water to a distance of 10° in every direction the January temperature should be 78·4° F. and the July temperature 43·3° F. Without further explanation such results may entirely destroy his faith.

Perhaps Mr. Brooks fears that x and y would revive painful recollections in the minds of geologists, and even a or b might touch a tender spot in their memories; but without the use of such terrifying symbols he could explain the logical foundation on which his method rests. He might also give some idea of the accuracy of the results that may be obtained from it, and the limits within which it may be safely applied.

The fact is that so far as existing temperatures are concerned, the figures in the table do not depend on any theory. They are obtained by a mathematical process, but that process simply selects the figures which will make the formula fit the facts most closely. The agreement is near enough to show that latitude, amount of land in the western semi-circle, etc., are dominating influences; but it is not precise enough to prove that other factors are of no importance. It is a reasonable presumption that small geographical changes will usually affect the influence of these other factors only to a small extent, and consequently the figures in the table will still give a good result. But if the changes are great this can no longer be said.

The geologist accordingly may accept with some confidence Mr. Brooks' conclusions with regard to such temperatures as those of the Littorina sea. When, however, he says that if the belt between 50° N. and 70° N. consisted entirely of land the "theoretical" January temperature of a point on 60° N. at sea-level would be − 30° F., the word "theoretical" simply implies that an attempt has been made to estimate the influence of all factors. But in so complex a matter such an estimate rests on a very insecure foundation. Moreover, remembering that in parts of Eastern Siberia the January (sea-level) temperature is below − 40° F. without an Ice Age, the geologist may still hold that the geographical theory of glacial periods is not yet proved.

It must not be supposed that any large part of the book is taken up by discussions of this nature, or that any special knowledge of meteorology is required to understand it. Evidence of all kinds is examined and summarized, and Mr. Brooks endeavours to show

how the changes of climate were brought about—how, for example, climatic conditions in the Mediterranean were connected with fluctuations of the ice-sheet farther north. The book, in fact, is a readable and interesting account of the changes in climate from the beginning of the Quaternary period to historic times.

At the end of each chapter there is a short bibliography. It would have saved the reader some trouble if the author had been more liberal with precise references for the statements in the text. Moreover, in assigning definite temperatures he does not always say whether they have been determined by his own method or are based on some other kind of evidence.

P. L.

THE PETROLOGY OF THE HAWAIIAN ISLANDS. By H. S. WASHINGTON. I. Kohala and Mauna Kea, Hawaii, Amer. Journ. Sci., vol. v, 1923, pp. 465–502. II. Hualalai and Mauna Loa, id., vol. vi, 1923, pp. 100–26. III. Kilanea and General Petrology of Hawaii, ibid., pp. 338–67. IV. The Formation of Aa and Pahoehoe, ibid., pp. 409–23.

ALTHOUGH a great deal has been written concerning the general vulcanology of the Hawaiian Islands, we possess little information as to the detailed petrology of the lavas, and the petrographical characteristics of the region as a whole. Dr. Washington has set himself to remedy this defect in a series of papers, partly based on material collected by himself and partly incorporating the previous work of others. A great number of analyses are given, together with concise descriptions of the macroscopic and microscopic features of the specimens analysed.

As a preliminary, a brief discussion is given of the meaning to be attached to the term basalt, which was restricted by Iddings to rocks containing olivine. With this view Dr. Washington, in common with the majority of petrographers, does not agree, and furthermore he uses the term andesite for some rocks with olivine, the criterion being that in the andesites the plagioclase dominates over the femic minerals, while in the basalts the proportions are more or less equal. Here arises a curious question, namely, the presence of olivine in certain rocks with a higher silica percentage than other rocks which do not carry this mineral. To explain this apparent anomaly recourse is had to the reaction that occurs in the pyroxene (clinoenstatite) molecule at a high temperature. Bowen and Anderson have shown that clinoenstatite melts incongruently, passing into olivine and liquid, this reaction being reversible, but it is suggested that in certain cases of rapid cooling the reverse transformation does not occur: in plain language, olivine is formed first in all types. If the cooling is slow pyroxene is formed from it, but in very rapid cooling there is not time enough for this to take place; and the olivine remains in unstable equilibrium. According to this

principle it is possible for phenocrysts of olivine to exist in a rhyolitic glass and for quartz to separate from the groundmass of an olivine basalt.

With the exception of two local occurrences of trachytes, apparently of early date, the rocks examined fall into the groups of andesites and basalts, as here defined. No free quartz appears to have been observed anywhere in the actual rocks, though in a few cases the calculated norm shows a small excess of silica. Some highly felspathic types are described as oligoclasite, while others show affinities to Harker's mugearites. The dominant lavas are however mainly characterized by more calcic plagioclase, andesine, and especially labradorite, while the pyroxene is diopsidic: biotite, hornblende, nepheline, leucite, and melilite have not been observed in Hawaii.

In these papers Dr. Washington has deliberately and wisely confined himself to the common rocks, avoiding descriptions of rare and "interesting" types, such as have in so many cases given a lop-sided impression of the petrography of a region. There are also some wise remarks on what the author calls the only too common disease of *cacoethes nominandi*. The most abundant type is an olivine-free basalt with labradorite, followed by andesine-basalt and then by oligoclase-andesite; olivine-basalts and olivine-andesites are less common, while there is a still smaller amount of a so-called picrite-basalt with about 50 per cent of olivine.

It is impossible here to give further details: it can only be said that these memoirs give a most valuable account of the general chemical and mineralogical characters of this important area. It is to be hoped that further papers will deal in equal detail with the other islands of the group, thus giving a complete picture of this petrographic province, which may probably be taken as typical of the larger Intro-Pacific region.

R. H. R.

Comagmatic Regions and the Wegener Hypothesis. By H. S. Washington. Journ. Washington Acad. Sci., vol. xiii, 1923, pp. 339–47.

An important feature in Wegener's hypothesis and in discussions thereon lies in attempts to fit together now disconnected portions of continents. Hitherto, however, no attention seems to have been paid to the important consideration as to whether the regions thus brought in contact show resemblances in composition and petrographical character as well as in form. Dr. Washington has undertaken this investigation with special reference to the Atlantic basin, where the correspondences in shape are the most satisfactory, though even there open to many objections, as pointed out by Lake and others. In the crucial case of the coasts of Guiana and northern Brazil on one side and the Gulf of Guinea on the other, sodic rocks are absent from one and quite abundant in the other. Further south

they occur on both sides and in some intermediate islands. Again, there is a resemblance between the late-Karroo (Stormberg) lavas of South Africa and plateau basalts in Brazil, Uruguay, and Patagonia. The correspondence between the supposedly adjoining portions of Europe and North America is however very slight, and the author concludes from his wide knowledge of the features of the various petrographical provinces that the study of the igneous rocks lends very little support to the Wegener theory.

Special Reports on the Mineral Resources of Great Britain. Vol. I: Tungsten and Manganese Ores. By H. Dewey, H. G. Dines, and others. Mem. Geol. Surv. Third edition, pp. iv + 80, with 3 plates. 1923. 2*s*. net.

IF at some future time, for a reason which cannot now be foreseen, there should arise in this country a demand for special metals, similar to what occurred during the late war, there will be no lack of information as to the resources actually or potentially available. With regard to tungsten, there is no doubt that in Cornwall the ore still occurs in great quantities, both in the yet unworked portions of the big tin mines and in many old mines that were abandoned at a shallow depth before the wolfram zone was reached. The exploitation of such ores must always prove a valuable auxiliary to the working of tin-lodes. In this memoir is given a very complete account, revised and brought up to date, of all known occurrences in the West of England, with two useful maps. An interesting account is also given of the tungsten lodes of Carrock Fell: the bearing of these lodes on the age of the Carrock intrusions has not yet been sufficiently considered by petrologists.

With regard to manganese ores, it can only be said that British resources are practically negligible, and there seems to be little prospect of a development, in time of stress, of low-grade home supplies, as was so successfully done in the United States during the war. Apparently we must always rely on imported ores.

R. H. R.

The Geology of the Country South and West of Shaftesbury. Explanation of Sheet 313. By H. J. Osborne White, F.G.S. Mem. Geol. Surv. iv + 112, with 4 plates and 11 figures. 1923. Price 3*s*. 6*d*. net.

IN this memoir the author has had the disadvantage of writing a memoir on the field-mapping of other persons, and naturally it becomes rather in the nature of a compilation. In the Inferior Oolite we find evidence given of the frequent breaks in the succession of the numerous non-sequences. An interesting case occurs where the "mainly calcareous upper beds of the Inferior Oolite pass laterally into the mainly argillaceous lower beds of the Fullonian in the short interval of 1½ to 3 miles". Such rapid changes of

facies must call for extremely delicate zonal determination to justify their acceptance.

The part of the memoir which will be of most interest to the majority of readers will probably be the short chapter on the Post-Cretaceous History of the District. Here the author is free from the work of compilation and is able to devote some pages to the Tertiary earth movements, their controlling influence on the development of the river systems, and on the formation of plateaux of varying ages.

The area is not one of much economic importance geologically, but everything which could possibly be put into this section appears to have been dragged in; even the pages on water supply appear to occupy much space for the amount of valuable information given.

The colour-printed map which this memoir explains is well printed on a good topographical plate.

MEMOIRS OF THE GEOLOGICAL SURVEY. SUMMARY OF PROGRESS FOR 1922. pp. i–iii, 1–164, figs. 1–6. Pub. Stationery Office, 4*s*.

THE Report for 1922 shows that in spite of reorganization, necessitating the drafting of District Geologists to districts more or less new to them, and the incorporation of many new inexperienced officers, work is still being maintained at the high level we have become accustomed to expect; this reflects the greatest credit upon all the Senior Officers, upon whom the training of the juniors falls of necessity, and leads us to expect great things in the future. The most interesting results under Section A (England and Wales) appear to have been achieved in the North, where the utilization of Goniatites as indices for the zonal subdivision of the Lower Coal Measures, Millstone Grit, and the beds below the Kinderscout Grit has been attended with considerable success. This work has been carried out along the lines indicated by Mr. W. S. Bisat at the Hull meeting of the British Association in 1922. It is most satisfactory to see work of this type being undertaken *officially*; it might with advantage be applied to other groups of the older rocks!

Another important result is the recognition of the Hersingham Grit as lying well within the Carboniferous Limestone Series.

In Section B (Scotland) the most important scientific results are petrological; these include most interesting details concerning the Tertiary igneous complex of Ardnamurchan, that would appear to have many affinities with those of Mull and Skye, and a summary of the petrographical work on the Island of Mull, which affords an indication of the good things that may be expected in the forthcoming memoir.

There are, in addition, two valuable appendices; the first deals with the concealed Mesozoic Rocks in South-west Norfolk; the second, by Dr. Spath, on the Ammonite horizons of the Gault and Contiguous Deposits, is a noteworthy contribution to the stratigraphical palæontology of these rocks.

G. L. E.

REPORTS AND PROCEEDINGS.

Geologists' Association.

4th January, 1924.

"The Blue Lias of the Devon-Dorset Coast." By W. D. Lang, M.A., Sc.D., F.G.S.

The Blue Lias comprises the limestones at the base of the Lias formation, and includes Oppel's *planorbis*, *angulatus*, and *bucklandi* zones. These zones have hitherto been but vaguely determined on the Devon-Dorset coast. Mr. Tutcher has recently established the following horizons in the Bath-Radstock area, namely, from below, upwards, *Volsella langportensis*, *Pleuromya tatei*, *Ostrea liassica*, *Psiloceras planorbis*, *Caloceras johnstoni*, *Waehneroceras megastoma*, *Alsatites liassicus*, *Schlotheimia angulata*, *Vermiceras conybeari*, *Coroniceras rotiforme*, *Coroniceras bucklandi*, *Paracoroniceras gmuendense*, *Aetomoceras scipionianum*; and, at any rate, the lower of these horizons have been found by Dr. Trueman on the Glamorganshire coast. The presence of all these from *Ostrea* upwards has now been recognized on the Devon-Dorset coast, although the demarcation between the *Coroniceras bucklandi* and the *Paracoroniceras gmuendense* zones has not yet been determined. In addition, a *Psilophyllites hagenowi* horizon has been recognized above the *Waehneroceras* horizon followed above by an *Alsatites laqueolus* horizon. The *Schlotheimia angulata* horizon has been re-named *S. marmorea*, for reasons given by Dr. Spath in his notes on the Ammonites mentioned in this paper. The limestones have been marked in detail on a map which includes the Devon-Dorset coast from Lyme on the east to the head of Pinney Bay on the west. This is on the scale of 25 inches to the mile, and is coloured to conform in general with the 25 inch maps to the east of Lyme published by the Association in 1914.

"On the origin of the battered Flint Spheres called 'Cannon Shots' from Norfolk." By F. N. Haward.

The generally accepted theory has been that these spheres were originally odd pieces of broken flint which were worn spherical by "Pot hole" or "Kettle hole" action under ice. The author suggests that this explanation is not necessarily correct, and that many of these spheres were originally "Fossil" balls in situ in the Chalk, and were excavated by nature and gradually battered and "noded" by surface movements of gravels at the end of the glacial period.

Mineralogical Society.

15th January.

A. F. Hallimond: The chemical classification of the mica group.

Muscovite and phengite can be represented as mixtures of the molecules $K_2O.3Al_2O_3.6SiO_2.aq.$ and $K_2O.(Fe,Mg)O.2Al_2O_3.6SiO_2.aq.$,

the amount of water being somewhat variable. The best-known lithia micas are represented as follows:—Lepidolite, $K_2O.Li_2O.2Al_2O_3.6SiO_2.aq.$; Cryophyllite, $K_2O.Li_2O.(Fe,Mg)O.Al_2O_3.6SiO_2.aq.$; Polylithionite, $K_2O.2Li_2O.R_2O_3.6SiO_2.aq.$ In the same way the dark micas can be represented as mixtures of phlogopite $K_2O.6(Mg,Fe)O.Al_2O_3.6SiO_2.aq.$, and two biotite types, namely $K_2O.4(Fe,Mg)O.2Al_2O_3.6SiO_2.aq.$ and $K_2O.6(Fe,Mg)O.2Al_2O_3.6SiO_2.aq.$ In the most acid biotites (from granite) the Al_2O_3 is somewhat greater, with a corresponding replacement of (Fe,Mg)O. Al_2O_3 is, of course, often replaced by Fe_2O_3, $(OH)_2$ by F_2, etc. Graphical formulæ of oxidic compounds (salts) can be simplified by writing the connecting group -O- as a single symbol. The above empirical formulæ can be represented as salts of the single-chain hexa-silicic acid with K,Mg,Fe, etc., and with a diacid alumina group $Al_2(OH)_2O$, in which hydroxyl is replaceable by fluorine. The greater acidity of the white micas is accounted for by the presence of three acid groups—Si:O:Si—in the chain; biotite results from the addition of 3(Fe,Mg)O to these groups, to form a normal salt; the most basic dark micas contain $Al_2(OH)_2O_2R$ in place of the simple group $Al_2(OH)_2O$, the aluminium becoming "amphoteric" when the solution is very rich in (Fe,Mg)O.

A. Brammall and H. F. Harwood: Gold and Silver as accessory minerals in the Dartmoor granite.

Visible gold occurs as scanty minute specks in a porphyritic oligoclase-quartz-orthoclase rock containing a pale green fibrous amphibole and abundant sphene, together with apatite, zircon, monazite, and, occasionally, tourmaline. The silver has not been observed in hand specimens; assays show that it is usually in excess of the gold. The rock occurs as large loose boulders on Bittleford Down and at a few other localities.

Arthur Russell: Topaz from Cornwall, with an account of the localities, old and new, at which it is found.

All the hitherto recorded occurrences of topaz in Cornwall are described, as also new ones at Castle-an-Dinas Wolfram Mine, St. Columb Major; Belowda Beacon Mine, Roche; Beam Mine, St. Austell; and Mulberry Mine, Lanivet. Crystals from most of the localities were measured and drawings are given with lists of forms. It is shown that at several localities topaz is present in considerable quantities in the cassiterite-wolfram lodes; at Belowda it is especially abundant with tourmaline.

Edinburgh Geological Society.

19*th December*, 1923.

1. "Notes on the Millstone Grit of the Central Coalfield of Scotland." By M. Macgregor, M.A., H.M. Geological Survey.

This series of rocks is of great importance not only directly, as a source of valuable fireclays, ganister, and sandstones, but also indirectly, as the cover under which search must be made for any

concealed areas of workable Limestone Coals. The Millstone Grit of this coalfield varies from a proved minimum thickness of only 8 feet to a maximum of over 1,000 feet. Lantern slides were shown to illustrate the surface distribution of the Millstone Grit, its thickness and character at different localities, the principal horizons of economic importance, and the marine bands—at least five in number—it is now known to contain. Special attention was directed to the remarkable attentuation of the Millstone Grit on the southern edge of the coalfield, and to the evidence for overlap and local erosion. The area towards which the Millstone Grit thins is the same as that in which the underlying Carboniferous Limestone Series also shows a notable decrease in thickness, and the suggestion was advanced that this phenomenon might be the result of a differential movement within the region of deposition. Not only was sedimentation less over this area, but in early Millstone Grit times it was slightly elevated and underwent, at least locally, a certain amount of erosion.

2. "Dumortierite in British Rocks." By Dr. Wm. Mackie, M.A., LL.D.

Dr. Mackie has found this rare mineral in a paragneiss near Newburgh, in a pegmatite near Ellon, in the Cowhythe gneiss, in a foliated granite near Portsoy, and in a Cornish granite.

3. "A Diopside-bearing Pegmatite from Ellon in Aberdeenshire." By H. H. Read, M.Sc., F.G.S., H.M. Geological Survey.

Pegmatites traversing a limestone at Michael Muir, near Ellon, have marginal zones rich in the lime-minerals, diopside, sphene, and apatite. The adjacent limestone is converted into a diopside-skarn. This contamination-process, like the widespread shale-contamination of gabbro, consists of a reciprocal reaction. By this, the pegmatite magma gains lime and the adjacent limestone gains silica. The low temperature at which this contamination takes place is noteworthy. Another example of the same contamination-process is supplied from Michael Muir by two open fissure-veins lined with large crystals of orthoclase and wollastonite, and similarly flanked by a diopside-skarn.

4. "Photograph and Note on River Deposit filling Cave at Blackford Hill." By T. C. Day, F.C.S.

A very interesting exposure has been brought to light on Blackford Hill; the spot is immediately adjacent to the well-known undercut and glaciated crag, where the true interpretation of polished and striated rock surfaces, so common in Scotland, was first demonstrated by Agassiz in 1840. A large shed which hid the eastern face of the crag has been removed revealing a small cave, filled from floor to roof with stratified river deposit. This deposit is due to the work of the Braid Burn: when running at a higher level it was cutting its way down through the mass of glacial deposits, which then filled the valley at this place.

16*th January*, 1924.

1. "The Geological Excursions of the British Association, 1923." By Dr. D. A. Allan.

During the meeting in Liverpool last September, a number of excursions were held to places of geological interest. The exposures revealed the Millstone Grit, Coal Measures, Permian and Triassic strata. Of the Post-glacial deposits, the Superior Forest Bed, with tree stems and roots, attracted attention. The most recent development of the topography was demonstrated near Great Crosby, where erosion has resulted in the destruction of valuable property. Thanks are due to Messrs. T. A. Jones and C. B. Travis, of the Liverpool Geological Society, for several of the views exhibited.

2. "Four Granitic Intrusions in S.E. Scotland." By Dr. F. Walker, B.A.

The Granites of Priestlaw and Cockburnlaw are intrusive into the Upper Silurian strata of the Lammermuir Hills, each igneous mass occupying an area of about one square mile. Both intrusions have centres of granodioritic composition, showing a gradual transition to porphyritic pyroxene-bearing quartz-diorites at the margin. Monoclinic pyroxene is common, but rhombic pyroxene is confined to the east margin of the Cockburnlaw mass.

Two smaller intrusions of granodiorite occur at Broad Law (near Heriot), and Lamberton Beach (near Burnmouth).

All four intrusions are very similar in their microscopical characters, and bear a close resemblance to some of the Galloway Granites. In three of them a curious porphyritic granodiorite occurs. At Priestlaw, this modification occupies the centre of the mass and passes outwards into true granitic types; which demonstrates that it did not owe its origin to marginal chilling.

Pebbles of two of the granites are found in conglomerates of Upper Old Red Sandstone age. All four show very little foliation, and their age may therefore be fixed as Lower or Middle Old Red Sandstone.

3. "Geology of the Coast between Kinkell Ness and Kingask, Fifeshire." By S. R. Kirk, B.Sc., St. Andrews.

The area described extends for about a mile eastwards from Kinkell Ness. The sedimentary rocks exposed on the shore platform are of the Calciferous Sandstone series and are penetrated by a number of old volcanic rocks. They are extensively folded and intersected by numerous small faults, mainly of the type due to tangential stress, viz. "transcurrent faults." For the most part these faults appear to be prior (in date) to the volcanic vents, but one instance is cited of a fault which is later than all the igneous activity, cutting through two of the vents and a dyke.

Four marine fossil zones are mentioned, and the suggestion is made that correlation of the "Myalina Bed" exposures further west (on Kinkell cliffs, at St. Andrew's Castle, and possibly also at Knock Hill) with the "Myalina Limestone" of Craigduff, ought

rather to be with a fossiliferous shale bed some 200 feet higher in the sequence.

Several interesting intra-formational phenomena occur among the sedimentary rocks. For the most part these are cases of "contemporaneous" erosion.

The smaller volcanic vents, to the east of the large Rock and Spindle vent, are found to be occupied chiefly by basic igneous intrusions, including, in parts, so much foreign fragmentary material as to give them the appearance of agglomerates. These vents contain evidence of earlier activity in the form of old ashes and tuffs, which are, in some cases, caught-up fragments in the intruded igneous rock.

At least two ages of intrusion can be recognized. The first includes the intrusive masses in the Rock and Spindle vent and in the second vent to the east of it. The second (apparently the final phase) includes dykes intersecting the first and traversing the sediments for considerable distances in the condition of "white trap". To this second age of intrusion the material, occupying the greater part of the orifices of the Craigduff group of necks, appears to belong.

Petrographically all these igneous rocks are allied. They may best be described as "Monchiquites", and are thus similar to the vent rocks of the St. Monans–Largo district.

Liverpool Geological Society.

8th January, 1924.

The following paper was read:—

"The Petrography of the Triassic Sandstones of South-West Lancashire." By Miss Stella W. Harris, M.Sc.

The paper records the results of a systematic investigation of the constitution of the Bunter and Keuper sandstones over an area 20 miles long by 10 miles wide, extending from Rufford on the north to Garston on the south, which Miss Harris has carried out in the Geology Department of Liverpool University, under the direction of Professor P. G. H. Boswell. For the purpose of comparison samples of Triassic rocks from the Wirral peninsula, the Vale of Clwyd, and the neighbourhood of Belfast have also been examined. The minerals noted are: Garnet, Magnetite, Anatase, Rutile, Zircon, Apatite, Hæmatite, Ilmenite, Quartz, Tourmaline, Barytes, Brookite, Topaz, Biotite, Epidote, Monazite, Muscovite, Orthoclase, Kyanite, Microcline, and Plagioclase. Of these, monazite and topaz have not hitherto been recorded in the Trias of the Liverpool district. Garnets are very rare, and have only been found at three localities in Bunter rocks. Staurolite has not been detected, although closely searched for. In mineral content, the Lancashire Trias is found to differ from that of the Midlands and South-West England, but to show great resemblance to the Trias of Wirral and the Vale of Clwyd, and also some similarity to that of Antrim and Arran. The paper concluded

with a discussion of the probable sources of origin of the material, and it was considered that the mineral assemblage in the Lancashire Triassic sandstones was suggestive of a north-western origin, although there may have been subsidiary drainage from other sources, and possibly some communication with the Midlands.

CORRESPONDENCE.

EOCENE CYCLES OF SEDIMENTATION.

SIR,—We trust you will allow us a little space to comment upon the reply of our friend, Professor Stamp, to our recent criticism of some of his published statements. It is true, as he points out, that writers sometimes find difficulty in expressing their views in an unambiguous manner, but this is as frequently the fault of the writer as of the reader. In making our criticism we did not attempt to read Professor Stamp's mind, although, in fact, we had ample opportunity of so doing in numerous private discussions. We restricted our remarks to statements in his published works, which are admirably clear and admit of but one interpretation, viz., that Wealden uplift was the essential cause of marine transgression in Eocene times. Indeed this has always seemed to us the distinctive feature of his theory. We need scarcely remark that we attached particular importance to the version given in his textbook, which is not only his most recent utterance on the subject, but is presumably a full and clear statement of his case expressly designed for the use of students.

We are told in Professor Stamp's reply[1] that uplift of the Wealden dome was merely an adjunct to wider movements of subsidence. In this connexion let Professor Stamp's words speak for themselves. In an introductory section on the Eocene rocks (*Introduction to Stratigraphy*, 1923, pp. 267–9), he says—

(i) That the formation of an anticlinal fold would cause the waters to spread in all directions over the deltaic deposits formed round the river mouths.

(ii) That "the history of the Eocene may be summarized as a succession of such movements. The intermittent but gradual uplift of the Weald seems responsible *in the main*".

So much for the "adjunct". The wider movements of subsidence now admitted by Professor Stamp only get an oblique reference in small type ten pages later, in the explanation of a diagram.

We are accused of missing his idea that Wealden folding and regional depression were almost synchronous. We missed it for the simple reason that this is the first clear reference to the matter made by him. No unbiassed reader could extract such a meaning from his previous writings.

[1] GEOL. MAG., Vol. LXI, 1924, p. 98.

His present account is far clearer, and we are in agreement with it in the main. Though he does not admit it, it is obvious that he realizes the justice of our former claim that " the influence of the Weald was neither as paramount nor as far-reaching as is implied by Professor Stamp's treatment ".

Coming now to questions of stratigraphical fact, we have yet to see that the Weald was being uplifted at all during Eocene times. Pre- and post-Eocene uplifts are clearly demonstrable, but Professor Stamp in his reply omits all reference to the conclusive fact that the Woolwich Beds overlap the Thanet Sands against the flanks of the Weald, and are in turn overlapped by the Blackheath Beds. If this is not evidence of continuous subsidence, we are concerned to know what is. None of the evidence of uplift adduced by Professor Stamp appears to us to be valid ; certainly none of it can reverse the conclusion drawn from the above facts—that Eocene times witnessed the progressive subsidence of the Weald, at least until the end of the London Clay period. Uplift may then have supervened in Bagshot times, as we have already admitted, but even of this there is no proof. We have already explained the Eocene pebble-beds as the rearranged beach deposits of a sinking shore line : we cannot accept the truly extraordinary theory which represents them as being literally shot down the flank of the Weald by uplift.

There are many other points on which we might join issue with Professor Stamp. It is certainly unjust to accuse us of rushing into print : many of our criticisms were framed before we undertook to read the proofs of the textbook. We advise those interested in the subject to read Professor Stamp's original articles and to compare them with his recent account. They will then, we feel sure, find our criticisms amply justified.

In conclusion we may say that the truth seems to be that Professor Stamp has now dropped the offending clause of his theory. He has retreated from the untenable position which resulted from his Wealden uplift idea. We are content if we have hastened, however slightly, the demise of this misleading idea. Clarified by its removal, his theory will certainly prove more acceptable to workers in Eocene stratigraphy. We may say quite definitely that we regard Professor Stamp's work as the most considerable contribution to the subject since the time of Prestwich, and we welcome its release from the unnecessary restrictions imposed upon it by his former published statements.

A. K. Wells,
S. W. Wooldridge.

THE HANGING VALLEYS OF NANT-FFRANCON.

Sir,—It was a disappointment to be absent from the reading of Professor O. T. Jones's recent paper on " The Upper Towy " at the Geological Society, for both paper and discussion were of keen interest to one who is working in North Wales. Perhaps I may be permitted to make a somewhat belated contribution to the discussion.

The "Arvon" country, between the Menai Strait and the Mountain Land is composed of the three platforms (at about 275, 430, and 550 feet respectively), which are described in *The Geology of Anglesey* (chapter xxxiv). In the course of my mapping of Arvon, I have been much impressed by the wonderful trenches which the Ogwen and its tributaries have cut through these platforms, and with the evident rejuvenescence of the rivers. In December last I was at a point whence one could look up to the remarkable "hanging valleys" of Nant-ffrancon, which have been ascribed to glacial over-deepening. Suddenly—the idea came like a flash—"What if these hanging-valleys be really due to the successive rejuvenations of the Ogwen?"

We have, however, to remember that there has also been some "re-senescence" (if one may coin such a term), owing to the 60 ft. subsidence which has let down the "Submerged Forest"; so that, before that, the total rejuvenescence was rather more than 600 ft. Now, the hanging valleys (as shown by Mr. Dewey) open out at 1,250 feet above sea-level. That is just about 600 feet above the floor of Nant-ffrancon! True, there may be 50 or 60 feet of drift and alluvium lying upon the rocky floor of that valley, but 50 or 60 feet is the least which can reasonably be assigned to glacial erosion. Thus we are left with a remarkable coincidence between the amount of the "hang" and that of the rejuvenescence of the Ogwen.

In which case (see "G. of A.", pp. 783–4) the hanging valleys may be assigned with much probability to Pliocene times. And they must be among the latest of the major pre-glacial features of the mountains. At that stage, therefore, Snowdonia was less deeply cut than it is to-day, and Snowdon itself was only some 3,000 ft. in height. Perhaps, by slow degrees, we may be able to trace out the successive stages of that prolonged erosion, which, beginning possibly in Miocene or Oligocene times, has developed the rugged mountain-region of North Wales.

EDWARD GREENLY.

MAN AND THE ICE AGE.

SIR,—In a previous communication treating of the great advance in our knowledge of the Pleistocene epoch due to Professor Depéret, reasons were given to show that the lowest gravels of the Somme terraces were deposited under genial conditions, and I should like now to call attention to the loess, which by its distribution, composition, and associated faunas would appear to be as definitely glacial, a conclusion established by the work of Sauer, Tietze, Krause, Wiegers, Werth, Lauterborn, Gagel, and Soergel. As a consequence Acheulean I, which occurs at the summit of the older loess, should be contemporaneous with the Riss glaciation, while the late Mousterian, which occurs at the base of the younger loess, should be assigned to the Würm. The early or warm Mousterian then readily falls into place in the Riss-Würm interglacial stage.

With the complete inversion of the views of Professor Penck concerning the "glacial" schotter and the "interglacial" loess, our difficulties in correlating the human industries of the Pleistocene are beginning to diminish or disappear. It is in particular most encouraging to observe that the ascertained correspondence of the Mousterian, at least in greater parts, with the Würm glaciation is in complete harmony with the views of Professor Marr and Mr. Reid Moir. The discovery of Mousterian implements in the Chalky Boulder Clay establishes the correlation of this deposit, not with the Riss, to which it is assigned by Professor Depéret, nor to the Mindel, to which it is assigned by Mr. Brooks, but with the Würm; a result perhaps unexpected but by no means surprising.

W. J. Sollas.

SPEETON AMMONITES.

Sir,—As an old and constant student of the Speeton Clays, I have been keenly interested in the recent capable revision of the Speeton Ammonoidea by Dr. L. F. Spath, and I desire to congratulate him on his results (Geological Magazine, February, 1924) which have cleared up many ambiguities and have materially strengthened the bases for correlation. One may perhaps be permitted to growl a little at having to struggle once more with a tangle of new nomenclature and synonymy, the disturbing concomitant of every successive revision; but one must strive to be heedful of the Scriptural monition so aptly quoted on occasion by J. F. Blake: "Thou shalt not muzzle the ox when he treadeth out the corn."

In dealing with the state of our knowledge of the Speeton Clays some months ago in a Presidential Address to the Yorkshire Geological Society (short abstract in Geological Magazine, March, 1923), I summed up the evidence regarding the age of the beds so far as it was then known. My conclusions and those of Dr. Spath are in agreement as to the sequence of the deposits, and, broadly, as to their correlation. We tend to differ, however, on certain minor points, as I am still inclined to hold that Dr. Spath, in limiting his investigation to the Ammonoidea, has hardly allowed enough for the fact that fossils of this order are absent or unknown from considerable portions of the sequence.

As it happens that the address referred to has not yet passed the press, I shall be able to add to it a few notes on Dr. Spath's work, bearing in particular on these points of divergence. Therefore, the discussion of detail would be redundant here, and it will suffice if I refer anyone desirous of pursuing the subject to the next issue of the *Proceedings* of the aforesaid Society.

It may be mentioned incidentally that the recognition by Dr. Spath of Lower Gault ammonites in the top beds at Speeton confirms my argument that Dr. Kitchin and Mr. Pringle were wrong in supposing (Geological Magazine, May, 1922) that the Lower Gault is absent there.

G. W. Lamplugh.

St. Albans,
6th March, 1924.